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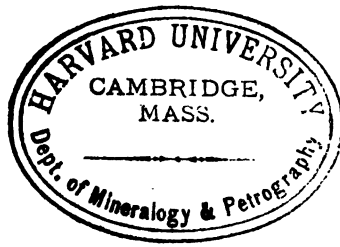
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Bulletin 640

CONTRIBUTIONS TO ECONOMIC GEOLOGY

(SHORT PAPERS AND PRELIMINARY REPORTS)

1916

PART I.—METALS AND NONMETALS EXCEPT FUELS

F. L. RANSOME AND HOYT S. GALE
GEOLOGISTS IN CHARGE



WASHINGTON
GOVERNMENT PRINTING OFFICE
1917

NOTE.—The Survey's annual volumes entitled "Contributions to economic geology" are issued in parts, and the last part will include a volume title-page, table of contents, and index for the use of those who may wish to bind the separate parts. A small edition of the bound volume will also be issued, but copies can not be supplied to those who have received all the parts.

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CONTRIBUTIONS TO ECONOMIC GEOLOGY, 1916.

PART I. METALS AND NONMETALS EXCEPT FUELS.

F. L. RANSOME and HOYT S. GALE, *Geologists in charge.*

INTRODUCTION.

The Survey's "Contributions to economic geology" have been published annually since 1902. In 1906 the increase in the number of papers coming under this classification made it necessary to divide the contributions into two parts, one including papers on metals and nonmetals except fuels and the other including papers on mineral fuels. In 1915 the year included in the title was changed from the year in which the field work reported in these papers was done to the year of publication, and in consequence there was no volume entitled "Contributions to economic geology, 1914." The subjoined table gives a summary of these bulletins.

United States Geological Survey "Contributions to economic geology."

Date in title.	Date of publication. ^a	Bulletin No.	Date in title.	Date of publication. ^a	Bulletin No.
1902.....	1903	213	1910, Part I.....	1911	470
1903.....	1904	225	Part II.....	1912	471
1904.....	1905	260	1911, Part I.....	1913	530
1905.....	1906	285	Part II.....	1913	531
1906, Part I.....	1907	315	1912, Part I.....	1914	540
Part II.....	1907	316	Part II.....	1914	541
1907, Part I.....	1908	340	1913, Part I.....	1915	580
Part II.....	1909	341	Part II.....	1915	581
1908, Part I.....	1909	380	1915, Part I.....	1916	620
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1909, Part I.....	1910	430	1916, Part I.....	1917	640
Part II.....	1911	431	Part II.....	1917	641

^a The date given is that of the complete volume; beginning with Bulletin 285 the papers have been issued as advance chapters as soon as they were ready.

As the subtitle indicates, the papers included in these volumes are of two classes—(1) short papers giving comparatively detailed descriptions of occurrences that have economic interest but are not of sufficient importance to warrant a more extended description; (2) preliminary reports on economic investigations the results of

which are to be published later in more detailed form. These papers are such only as have a direct economic bearing, all topics of purely scientific interest being excluded.

Brief abstracts of the publications of the year are given in the annual report of the Director. The complete list of Survey publications affords, by means of finding lists of subjects and of authors, further aid in ascertaining the extent of the Survey's work in economic geology.

The reports on work in Alaska have been printed in a separate series since 1904, the volumes so far issued being Bulletins 259, 284, 314, 345, 379, 442, 480, 520, 542, 592, 622, and 642.

DEPARTMENT OF THE INTERIOR

FRANKLIN K. LANE, Secretary

UNITED STATES GEOLOGICAL SURVEY

GEORGE OTIS SMITH, Director

Bulletin 640—A

NOTES ON THE PROMONTORY DISTRICT, UTAH

BY

B. S. BUTLER AND V. C. HEIKES

Contributions to economic geology, 1916, Part I
(Pages 1-10)

Published March 16, 1916



WASHINGTON
GOVERNMENT PRINTING OFFICE
1916

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NOTES ON THE PROMONTORY DISTRICT, UTAH.

By B. S. BUTLER and V. C. HEIKES.

INTRODUCTION.

The following notes on the Promontory district are the result of a visit by the writers in August, 1915. Through the courtesy and with the guidance of Mr. S. S. Arentz, manager of the Lake View Mining Co., a much better idea of the geology was obtained than would otherwise have been possible in the time available. Mr. Arentz has described the Lake View Mining Co.'s property in a report to that company,¹ and in the following pages free use has been made of his descriptions, as well as of other data furnished by him.

GEOGRAPHY.

The Promontory district is in Boxelder County, Utah, near the south end of the Promontory Mountains, a range that forms a long promontory on the north shore of Great Salt Lake. (See fig. 1.) The south end of the promontory is crossed by the Lucin cut-off of the Southern Pacific Railroad. Promontory Point station is on the east side and Saline station on the west side of the promontory. Saline serves the portion of the range in which ore deposits have been developed. The camp is about 25 miles south of Promontory station on the old line of the Southern Pacific Railroad.

The area in which ore has been produced is 3 to 4 miles north of the railroad and at an elevation about 1,000 to 1,500 feet higher. The wagon road has a moderate grade for most of the distance but is rather steep near the camp. Wagons and a motor truck were used in hauling ore to the railroad and supplies to the camp. The haul from the camp is almost entirely down grade.

The range supports a rather scanty growth of cedar and other scrubby trees which are available as a fuel supply.

There are some springs on the south end of the promontory but none near the camp. At the time of visit water was brought in on the railroad for the section crew at Saline and the Lake View mining camp. An attempt will doubtless soon be made to develop a supply of water near by.

¹ Salt Lake Min. Rev., vol. 17, pp. 12-15, 1915.

The camp of the Lake View Mining Co., owners of the only producing claims of the district, is located on a beach of Lake Bonneville, the predecessor of the present Great Salt Lake. This old beach forms a bench on the mountain side and affords a level and very beautiful camp site overlooking Great Salt Lake.

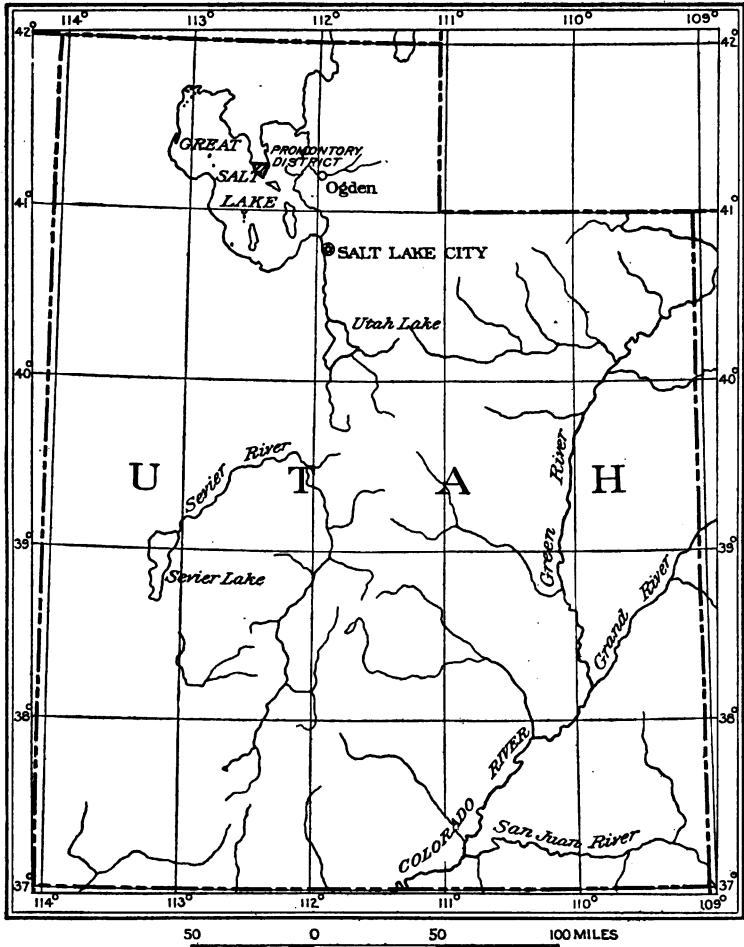


FIGURE 1.—Index map showing location of the Promontory district, Utah.

GEOLOGY.

No detailed description of the geology of the Promontory Range has been published. The range lies within the area covered by the Fortieth Parallel Survey and was examined by Hague, from whose description the following quotation is taken:¹

This range extends from the northern limit of the map about 45 miles to the southward, forming a rocky promontory, which divides the two northern arms

¹ Hague, Arnold, U. S. Geol. Expl. 40th Par., vol. 2, pp. 420-423, 1877.

of Salt Lake, with a varying width from 4 to 7 miles and reaching in its highest point 3,000 feet above the level of the lake. North of the railroad the range is comparatively low, with rounded outlines, the greater part of its surface being covered with loose soil and grass and showing but few outcrops. The underlying formation, however, belongs to the Wahsatch limestone and is evidently a continuation to the northward of the same beds which characterize the more important portions of the range projecting into the lake. The railroad passes through a low depression in the range, which on the summit attains an altitude 4,943 feet above sea level, or over 700 feet above the level of Salt Lake. The old Pliocene Lake, at its highest elevation, unquestionably occupied this pass, isolating the main portion of the Promontory Mountains, which formed an island of greater extent than either Stansbury or Antelope Island. This gap in the range at its widest expanse measures about 3 miles in a north and south direction and everywhere shows the rounded forms and broad, level benches produced by recent erosion and former occupation by the lake waters. On both the north and south sides of the gap the upper terrace lines of the old lake are quite marked, but perhaps less continuous than at other localities. All along the east and west sides of the Promontory Mountains these old terraces and beach lines may be traced with more or less distinctness, indicated by loose deposits of sand and gravel or by benches cut in the hard mass of limestone. The elevation of the highest of these terraces is approximately 940 feet above the present level of the lake. To the south and west of the railroad, at Promontory station, the range, which is quite narrow, consists of a series of limestones of a prevailing gray color, in the lower part of which are dark, heavy beds of nearly black limestone, all dipping to the westward at an angle of 38° . About 4 miles south of Promontory station the range widens rapidly to the westward, attaining a width of 6 to 7 miles, of which the western third is occupied by the same series of limestones, which here rise with an easterly dip and overlie a limited outcrop of Archean schists.

These Archean rocks are exposed on the southwest corner of this projection of the range and consist of quartzites and mica-bearing schists, closely resembling those described in the Archean bodies of the Wahsatch. The main crest to the east of this western projection is occupied by conformable strata dipping, as already mentioned, about 38° to the west. They are much contorted and show more or less faulting, so that their thickness can not be accurately determined. It is, however, not less than 3,800 feet. About the middle of the series there is an included zone of yellowish-brown sandstone, more or less calcareous, within which are several beds of gray limestone. Its lower portion is sharply defined from the underlying limestone, but 300 feet above, where it passes again into the limestones, it shades off gradually through shaly beds. The general strike of this portion of the range is N. 28° E.

Along the extreme eastern foothills, on the edge of the lower Quaternary plain, which borders the lake shore, are outcrops of easterly dipping beds, which evidently show a portion of the eastern half of an anticlinal fold, of which the main mass just spoken of is the western member. This anticlinal fold appears very distinctly in the group of hills about 8 miles south of Promontory station, of which Benada Peak is the culminating point. Here a distinct northern axis cuts the range, and south of that point the rocks dip to the eastward. Through the pass, about $1\frac{1}{2}$ miles north of Benada Peak, passes a synclinal axis quite parallel to the anticlinal, which lies 1 or $1\frac{1}{2}$ miles to the west of it. Here the easterly dipping members of the western anticlinal and the westerly dipping parts of the eastern or second anticlinal meet. The second anticlinal passes through Benada Peak itself, and, as has been said, to

the south of that point, for about 12 miles down the range the greater part of the limestones dip uniformly to the east at angles varying from 20° to 40°. At Flat Rock Point, on the west side of the range, are found portions of the western members of this anticlinal fold, dipping at a gentle angle into the lake and consisting for the most part of gray and drab limestones, among which are intercalated bands of yellowish-brown sandstone similar to that described in the westerly dipping mass south of Promontory station.

From the westerly dipping limestones about 5 miles south of Promontory station, near Antelope Springs, were obtained the following fossils: *Productus prattenianus*, *Spirifer opimus*, *Athyris subtilita*, *Streptorhynchus* (fragments); while the limestones farther south afforded *Zaphrentis stansburyi*, *Productus semireticulatus*. These fossils are all clearly of Carboniferous age, though of themselves not distinctly characteristic, either of the Upper or Lower Coal-Measure limestones. The thickness of the series and its relation to the underlying Archeans, however, as well as its general lithological character, all serve to ally it rather to the latter division.

About 14 miles south of Benada Peak the Carboniferous limestones are found to abut unconformably upon a series of Archean schists, which occupy the whole lower 7 or 8 miles of the range, with a strike N. 30°-35° W. and a dip to the northeast. The Archean strata consist largely of siliceous schists and imperfectly bedded hornblendic and micaceous gneisses, together with thick beds of quartzite and more or less interspersed argillaceous schists. Just west of the southernmost extremity of the range the Archean rocks come nearly down to the water's edge, presenting a cliff, some 50 feet in height, of dark argillaceous schist, which has apparently a dip of 25° to the west.

The above description of the south end of the promontory was apparently based on an examination along the western base, for in the central and eastern parts limestone is the most abundant rock.

Only the rocks forming the central portion of the series exposed were examined by the writers. The sedimentary rocks show the general stratigraphic succession discussed below.

According to Hague the basal formation of the range is made up of Archean schists. This formation is overlain by a great series of quartzites whose thickness has not been determined but is at least several thousand feet. The quartzite series is believed to be the equivalent of the Cambrian and Algonkian quartzites and shales in the Wasatch Range, which vary in thickness but in Big Cottonwood Canyon exceed 10,000 feet. Above the quartzite comes a succession of shales, impure limestones, and sandstones, with some beds of rather pure limestone toward the top of the series. This group attains a thickness of 700 to 800 feet. The accompanying section (fig. 2), based on data furnished by Mr. Arentz, shows the character of the sediments in this group. Above this series there are heavy-bedded limestones which attain a thickness of several thousand feet. These limestones were not examined.

Fossils were collected from the shale series overlying the quartzite and from the shale above the "middle bed," as the limestone in which the ore deposits have been developed is locally called. These were

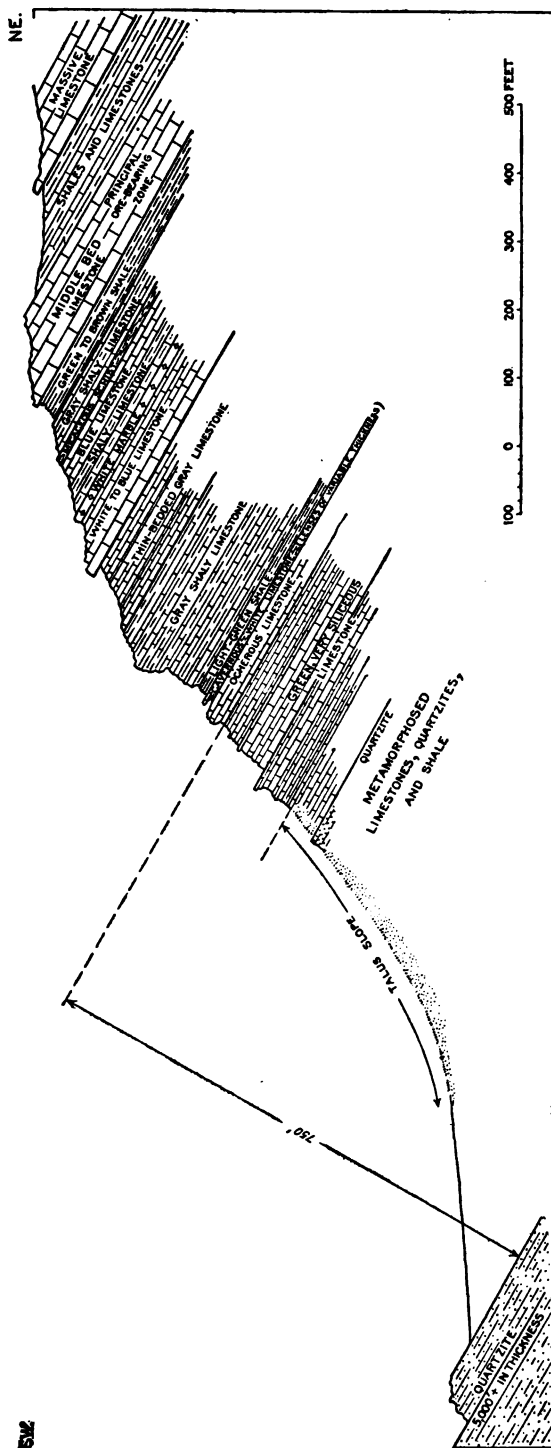


FIGURE 2.—Section showing stratigraphic succession of the sedimentary rocks in a portion of the Promontory district, Utah.

examined by Edwin Kirk, of the United States Geological Survey, who made the following report:

The fossils are not in a very satisfactory state of preservation, but approximate determinations are possible. All the evidence points to the lower Middle Cambrian age of the fossils.

Lot No. 1. Shale, 100 to 400 feet above lower "big" quartzite, about a quarter of a mile north of Lake View camp:

Ptychoparia sp.

Bathyuriscus sp.

Lot No. 2. South of Lake View camp, in shale above "ore limestone":

Micromitra (*Iphidella*) *pannula* (White).

Lot No. 3. In shale above (?) ore bed; collected by S. S. Arentz:

Zacanthoides sp.

Lot No. 4. Float from shale above quartzite:

Neolenus cf. *N. superbus* Walcott.

Bathyuriscus cf. *B. productus* Hall and Whitfield.

Lot No. 5. Shale above "ore limestone" south of Lake View camp:

Ptychoparia sp.

Algæ.

Lithologically and paleontologically the rocks between the quartzite and the upper limestone series rather closely resemble the series of shales and limestones occurring at a similar horizon in the Wasatch, Oquirrh, Tintic, and other ranges, though both the shales and the limestones are more abundant in the Promontory Mountains than in any of the other ranges mentioned. Limestone is, however, even more abundant at this horizon in northeastern Utah.

The age of the beds has been determined from the fossil evidence and correlation with other areas. The upper part of the quartzite series is doubtless of Cambrian age, and the lower part may be Algonkian, though this has not been determined. The limestone and shale series overlying the quartzite is of Cambrian age, as determined by the paleontologic evidence. The age of the upper limestone probably ranges from Cambrian to Carboniferous.

No igneous rocks were observed in the vicinity of the mineralized area. Mr. Arentz states that a dike 4 feet in width and traceable for about 150 feet cuts the heavy-bedded limestones east of the Lake View property. In the hand specimen this is a dark-green rock apparently having the composition of a rather basic diorite or possibly diabase. Similar rocks are said to cut the quartzite west of the Lake View property.

The general structure of the range at the south end is monoclinal. The beds strike about N. 40° W. and dip 30°-40° N. As indicated by Hague's description of the part of the range farther north, this apparent monocline may be the eastern limb of an anticline from which the western portion has been removed by erosion. Some indication that such is the case is given by a small area of westward-dipping sediments near the south end of the promontory. Minor

faulting in northerly and easterly directions has taken place, but so far as observed the displacement is at most but a few feet. About 6 or 7 miles north of the south end of the range there is apparently a strong east-west break along which the portion to the south has been relatively depressed. This feature was observed only from a distance, and no details concerning it are known. Fissures striking about due north, with a steep westerly dip, are rather abundant through the area where prospecting has been carried on.

ORE DEPOSITS.

HISTORY OF PRODUCTION.

Prospecting in the range up to the time of visit had been largely confined to two localities, both near the southwest side of the promontory. There has been some prospecting of copper deposits in the quartzite series on the west side of the promontory about $1\frac{1}{2}$ miles northwest of Saline over a period of several years. In 1907 14 tons of hand-sorted ore, averaging 3.85 per cent of copper and 1 ounce of silver to the ton, was shipped. The present activity is confined largely to the zinc-lead deposits. The history of these deposits is given by Mr. Arentz as follows:¹

For several years previous to 1915 a coterie of Ogden men, headed by Mr. James Wortherspoon, Lorenzo Farr, John Farr, and Mr. Carlson, held two groups of placer claims covering a bed of marbleized limestone, and also a large portion of what is now the Lake View Mining Co.'s property. This placer property was held by location over a period of some five years; the amount of work done was almost negligible. December, 1914, several men, headed by I. F. Farr, were employed to work on this placer property on the marble outcrop, about 1 mile north of the Judge Henderson wheat field. During noons and Sundays the workmen walked up the wash to the limestone beds outcropping above. Boulders of lead-zinc carbonate were discovered in the talus and traced to the outcrop of ore in place found at the top of the 100-foot bed of limestone, forming the so-called middle bed in contact with shale. Four locations were then made by Charles Johnson, I. F. Farr, and Lorenzo Farr. Charles Johnson sold out his interest to Mr. P. A. Mattson, who was then superintendent of the Henderson ranch. A few holes were dug on the outcrop by these men. Early in January Mr. W. A. Perkins, of Ogden, joined as a fourth partner, and a total of four 4-foot holes and open cuts were opened up and some ore piled for shipment.

After an examination made in February of this year [1915] by Samuel S. Arentz, of Salt Lake, a fifth interest was negotiated for and obtained on March 9. Mr. Arentz began operations as one-fifth owner and under contract to manage the mine for one year.

The Lake View Mining Co. was then incorporated for 500,000 shares, par value 5 cents, and the following board elected: Lorenzo Farr, president; P. A. Mattson, treasurer; I. F. Farr, secretary; W. A. Perkins and S. S. Arentz, directors.

¹ Salt Lake Min. Rev., vol. 17, p. 12, 1915.

Your company has sold no stock, began operations without money in the treasury, all expenditures made by the original owners have been returned to them, and from the first of May, less than sixty days after beginning of operations, it has been self-supporting.

The net weight of ore shipped to August 1, 1915, was 1,961,900 pounds, averaging as follows:

Content of ore shipped from Lake View Mine.

	Per cent.		Per cent.
Lead-----	7.7	Zinc-----	32.75
Iron-----	1.1	Sulphur-----	.2
Silver-----	.2	Molsture-----	1.9
Gold-----	Trace.	Insoluble-----	16.0

The gross returns for 21 cars were \$35,636.75.¹ The company reported that it had paid dividends of \$8,119.75 to August 1 and had a net balance of \$7,180.14.

ZINC AND LEAD DEPOSITS.

Prospecting of zinc and lead deposits at the time of visit had been confined almost entirely to the "middle" limestone bed. (See fig. 2.) As noted in the discussion of the geology, this is a limestone bed 50 to 75 feet in thickness included in members composed prevailingly of shale. The ores have been formed by replacement of this limestone near the north-south fissures. The largest deposits thus far disclosed occur just beneath the overlying shale, though developments have shown that considerable mineralization has taken place at lower horizons in the ore-bearing limestone. The ores are entirely oxidized, consisting of zinc and lead carbonates and a little hydrous iron oxide and manganese oxide. The gangue consists mainly of unreplaced limestone with some quartz.

As the writers' observations were confined to very shallow developments, it is not possible to make any generalizations concerning the relations of the ores. The carbonate ores were undoubtedly derived from the alteration of sulphides, though no sulphide was observed.

It has been found a pretty general rule that in the oxidation of mixed lead and zinc sulphides in limestone the oxidized lead ores occupy essentially the position of the original sulphides and the zinc ores have formed beneath the original sulphide bodies.² The zinc sulphate produced by the oxidation of the sulphides has passed into the underlying limestone, with which it has reacted to form the

¹ It is reported that to the end of 1915 the Lake View Mining Co. had produced ore for which \$138,737 was received. Of this amount \$65,000 was paid in dividends and \$16,000 remained in the company's treasury.

² Butler, G. M., Some recent developments at Leadville; the oxidized zinc ores: Econ. Geology, vol. 8, p. 1, 1913. Knopf, Adolph, Mineral resources of the Inyo and White mountains, Cal.: U. S. Geol. Survey Bull. 540, p. 81, 1914. Loughlin, G. F., The oxidized zinc ores of the Tintic district, Utah: Econ. Geology, vol. 9, pp. 1-19, 1914.

zinc carbonate. The chemistry of this process has been discussed in the papers cited and need not be set forth here.

In the Promontory district, so far as developments show, zinc is far more abundant than lead, and it is possible that this was true in the sulphide bodies. The relation of the zinc and lead ores in some places corresponds to that found in other districts, namely, the zinc lies below the lead; but there are other places where this does not appear to be the case. A determination of the general relations must await further developments. Mr. Arentz¹ has pointed out that from the crests of the spurs, through which the ore bed passes, toward the canyon bottoms there is a progressive decrease in the content of zinc and an increase in lead.

Prospecting has been carried on along the outcrop of the "middle bed" for a distance of about 4,500 feet, and bodies of ore are shown in numerous openings. In the development of the property the managers seem to have followed the conservative policy of determining the amount and character of the mineralization along the outcrop before beginning extensive developments at depth, and at the time of visit the ore zone had nowhere been exposed more than a few feet below the surface. Sufficient data concerning the mineralization had been obtained, however, to warrant the planning of deeper development work. The region is one of considerable relief and suited to the development of the ore bed for several hundred feet below its highest outcrop by means of tunnels. Practically no work has been done on the lower limestone, though it is said to contain as much as $3\frac{1}{2}$ per cent of zinc on the outcrop.

COPPER DEPOSITS.²

The copper prospects of the Promontory district are about $1\frac{1}{2}$ miles northwest of Saline station. The deposits crop out on the crest of a ridge near the shore of the lake. The country rock is the quartzite near the base of the exposed sedimentary rocks of the south end of the range. The beds at this point strike N. 45° – 50° E. and dip 16° – 20° SE. The ore is disseminated in the quartzite. The primary mineralization formed chalcopyrite and possibly bornite, but at the surface the sulphides have been altered to carbonates.

The developments consist of two shafts about 200 yards apart, sunk from the crest of the ridge. One of these has a depth of about 50 feet, the other of 120 feet. At a lower point an inclined shaft was sunk on a westerly pitch nearly at right angles to the dip of the beds to a depth of 80 feet. Near the same point a tunnel has been driven eastward for about 100 feet. At a point near the shore of Great

¹ Salt Lake Min. Rev., vol. 17, p. 13, 1915.

² The statements concerning the copper deposits are based on observations by Mr. Heikes and information furnished by Mr. C. A. Redfield, of Ogden, Utah.

Salt Lake and about 200 feet vertically below this tunnel another tunnel has been driven eastward for 452 feet. This was projected to intersect the downward extension of the ledge that crops out on the ridge.

Some mineralized rock was observed in the prospect openings, and it is said that more valuable ore was encountered at some points which were not accessible at the time of visit. The ore shipped was obtained from large blocks of mineralized quartzite at the surface. These blocks measured from 15 to 50 feet in thickness.



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RECONNAISSANCE OF THE
CONCONULLY AND RUBY MINING DISTRICTS
WASHINGTON

BY

EDWARD L. JONES, JR.

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NOTE.—The Survey's annual volumes entitled "Contributions to economic geology" are issued in parts, and the last part will include a volume title-page, table of contents, and index for the use of those who may wish to bind the separate parts. A small edition of the bound volume will also be issued, but copies can not be supplied to those who have received all the parts.

RECONNAISSANCE OF THE CONCONULLY AND RUBY MINING DISTRICTS, WASHINGTON.

By **EDWARD L. JONES, Jr.**

INTRODUCTION.

FIELD WORK AND ACKNOWLEDGMENTS.

This report is based on a hasty examination of the Conconully and Ruby mining districts, in Okanogan County, Wash., made during two weeks in June, 1915. In the short time available for the work detailed geologic mapping of the complex rock formations was impossible. The districts are included in the Okanogan and Chopaka quadrangles, which have been topographically mapped by the United States Geological Survey. The maps of these quadrangles form the base for the map of the districts given herewith (Pl. I), on which the locations of mines and prospects are shown and the contact between the granite and metamorphosed rocks is indicated for a distance of 10 miles.

The writer expresses his thanks to the members of the Conconully Miners' Association for data and assistance in the field, and to Prof. Francis A. Thomson, of the State College of Washington, who has furnished a preliminary report on the metallurgic treatment of the ores which is largely incorporated in this paper. Data on the Arlington mine were kindly supplied by Mr. H. S. Stoolfire, of Spokane, Wash.

PUBLICATIONS.

G. A. Bethune, the first State geologist of Washington, in his report for 1890 first describes the Ruby and Salmon River mining districts. Henry Landes, in volume 1 of the State Geological Survey of Washington, gives a brief economic account of the Conconully district. J. B. Umpleby, in Bulletin 5 of the State Geological Survey, gives a report on the Oroville-Nighthawk area, of which the Palmer Mountain district, lying immediately north of the Conconully district, is a part. The region to the north and west along the international boundary has been described also by Smith and

Calkins¹ and by Daly.² Bailey Willis³ passed through the Okanogan Valley in 1887 and made many notes on its physiographic features.

HISTORY.

Okanogan County west of Okanogan River comprised part of the Moses Indian Reservation. Although the reservation was known to contain mineral deposits, it was not opened to prospecting until 1886. In that year, because of the discoveries of high-grade silver-lead ores, the Salmon River district was organized and in the year following the Ruby mining district. For several years development was active, and the Ruby, Arlington, First Thought, Fourth of July, and Last Chance mines in the Ruby district are estimated from reports to have produced \$200,000 worth of ore. The Salmon River district, centering about Conconully, is also credited with a small production. Many factors contributed to the decay of these districts, such as the lack of railroad facilities and the decline in the price of silver. Of the town of Ruby there remain only old foundations and two dismantled mills, which were reported to have had little success in the concentration of the low-grade ores.

With the completion of the railroad interest in mining has revived, and several companies are now engaged in the development of their properties. One, the Arlington, has made several shipments of smelting ores. Natural conditions are very favorable for mining in these districts. Wood for mine timbers and fuel is abundant, and electric power could be generated from Salmon Creek or purchased from the plant on Similkameen River near Oroville.

GEOGRAPHY.

LOCATION AND ACCESSIBILITY.

The Conconully and Ruby mining districts lie in the central part of Okanogan County, Wash. (See fig. 3.) Conconully, formerly the county seat, a town of 200 inhabitants, is situated at the southern end of the Conconully district and is best reached from Riverside, a station 12 miles east on the recently constructed branch of the Great Northern Railway that traverses the Columbia and Okanogan river valleys between Wenatchee and Oroville. Good wagon roads lead from Conconully to points in the Okanogan Valley. The old town site of Ruby, 5 miles south of Conconully, is near the center of the Ruby district, which, however, is not very definitely bounded.

¹ Smith, G. O., and Calkins, F. C., A geological reconnaissance across the Cascade Range near the forty-ninth parallel: U. S. Geol. Survey Bull. 235, 1904.

² Daly, R. A., The Okanogan composite batholith of the Cascade Mountain system: Geol. Soc. America Bull., vol. 17, pp. 329-376, 1906.

³ Willis, Bailey, Changes in river courses in Washington Territory due to glaciation: U. S. Geol. Survey Bull. 40, 1887.

TOPOGRAPHY.

RELIEF.

The Ruby and Conconully districts lie in the borderland between the Okanogan Mountains, the eastern division of the Cascade Mountain system, on the west, and the old erosion surface, later uplifted and now designated the Okanogan highlands, which flanks this range on the east. The Okanogan Mountains lie between Okanogan and Methow rivers. Their highest peak, Tiffany Mountain, is 8,275 feet

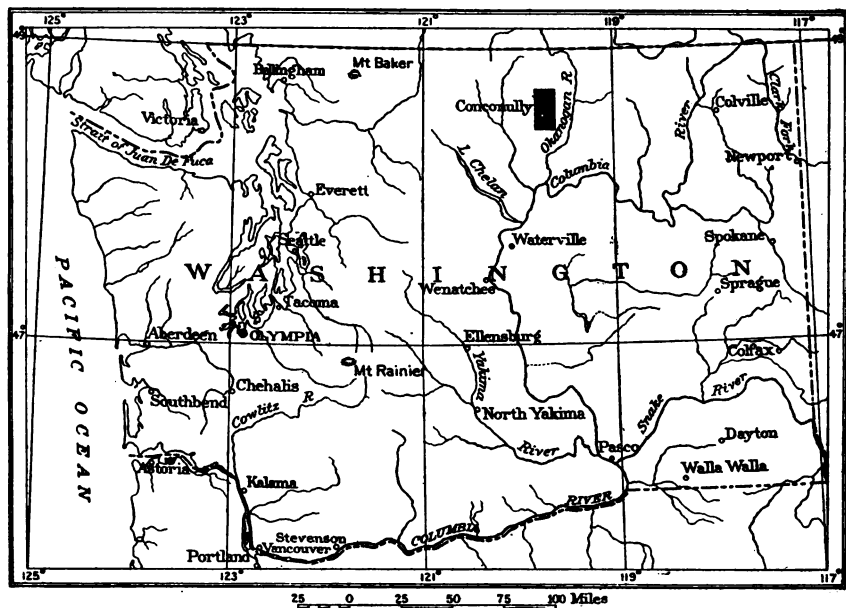


FIGURE 3.—Index map showing location of the Conconully and Ruby mining districts, Wash.

above sea level. Altitudes near Conconully range from that of Conconully Lake, 2,287 feet, to the summit of Mineral Hill, 5,500 feet, but few of the higher summits of the rolling country east of Conconully exceed 3,500 feet in elevation.

PENEPLANATION.

The old erosion surface of the Okanogan highlands has been correlated by Umpleby¹ with the interior plateau region of Canada, which has been described by Dawson,² and also with an erosion surface near Republic, Wash.¹ Umpleby regards the age of this surface

¹ Umpleby, J. B., Washington Geol. Survey-Bull. 5, pp. 61-62, 1911.

² Dawson, G. M., Roy. Soc. Canada Trans., vol. 8, sec. 4, p. 11, 1890.

as essentially Eocene. Dawson, however, recognized two erosion cycles which gave to the interior plateau its topographic form. The older cycle he regards as Eocene and the younger as post-Miocene. Smith and Calkins² and Smith and Willis³ have described an erosion surface which truncates Miocene lavas in the Cascade Mountains to the west and south, respectively, of the area. The post-Miocene plantation in adjacent areas and the occurrence near Oroville of Miocene lake beds that are now a part of the upland surface are regarded by Smith as evidence that the Okanogan highland surface was formed for the most part in post-Miocene time. The determination of the age of the peneplain throws light on the age of the granite intrusions and the ore deposits. Umpleby observed near Oroville that the eastern borders of the batholith have been carved by this erosion, although the peneplain is not recognized in the more rugged parts of the Okanogan Mountains. The age of the Similkameen granite is therefore pre-Miocene and possibly pre-Eocene.

DRAINAGE.

The mountainous and highland areas are deeply incised by valleys which contain actively flowing streams, and by others, locally termed "coulees," which contain no streams at present but were former drainage channels. These channels have been ascribed to stream cutting during the occupation of this area by the Okanogan Glacier and during the time of its retreat. Salmon Creek, which flows southward, drains the larger part of the area covered by this reconnaissance; Sinlahekin Creek, which flows northward to Similkameen River, bounds the area at the north, and Johnson Creek flows across the central part and turns south along the eastern limit of the area examined.

Conconully Lake, a long, narrow body of water, lies in a north-south depression which extends from Conconully northward beyond this area to Similkameen River. Glacial débris has been deposited in this depression, and several small lakes that have no surface outlets occur at the north end of the area a short distance south of the point where Sinlahekin Creek turns and flows northward in this valley.

About 2 miles south of Conconully the United States Reclamation Service has dammed Salmon Creek at a point where the stream enters a narrow canyon. The reservoir thus formed extends northward to the town and covers a part of Graveyard Flat to a reported maximum depth of 100 feet. The flood waters of spring are thus

¹ Umpleby, J. B., Washington Geol. Survey Bull. 1, pp. 19-20, 1910.

² Smith, G. O., and Calkins, F. C., U. S. Geol. Survey Bull. 235, p. 90, 1904.

³ Smith, G. O., and Willis, Bailey, U. S. Geol. Survey Prof. Paper 19, 1903.

conserved for the irrigation of bench lands overlooking Okanogan River.

GLACIATION.

Evidences of extensive continental glaciation in this region are apparent to elevations of 7,500 feet. Over the Okanogan highlands much glacial débris has been deposited, so that in many places small lakes have been formed and stream courses changed. Similkameen River is thought to have been deflected by glacial agencies and now joins Okanogan River at a point many miles north of its former confluence. Deposits of sand in the Salmon Creek canyon near Conconully were probably formed during a temporary ponding of the stream, and large drift boulders and smooth, bare surfaces of the granite high up on Ruby and Mineral hills are further evidences of glaciation.

VEGETATION.

Much of the drift-covered highlands area east of the Conconully-Sinlahekin depression is devoid of timber and is largely used for agriculture, but west of this depression the higher slopes are covered with good growths of timber, of which yellow pine and fir are the most abundant varieties. Rock outcrops are well exposed on the steep hillsides of the drainage channels, but are sparsely distributed over the greater part of the highlands area.

GEOLOGY.

ROCKS OF THE AREA.

The geology of this area is complex, and a satisfactory solution of the problems involved would require a thorough study of the surrounding region. In general the rocks comprise an older series of metamorphic rocks which has been intruded by later granite masses, the largest of which is the great batholith west of Conconully. The metamorphic rocks are schists derived from sedimentary rocks, quartzite, and marble, associated with schistose or gneissoid igneous rocks of varying composition. The highlands area contains no large intrusive masses, but is underlain chiefly by the metamorphosed rocks.

SEDIMENTARY ROCKS.

KINDS AND DISTRIBUTION.

The sedimentary rocks and their metamorphic derivatives consist of schists, quartzites, and limestones. The schists are prominently developed along the eastern border of the batholith from Ruby Hill to Conconully and west of the Conconully-Sinlahekin

depression to the north boundary of the district. They are of different kinds. Some are fine grained and thinly laminated in shades of black, gray, and brown; others are coarse banded micaceous rocks that are evidently altered sandstones and in some localities grade into or include fine-grained sericitic quartzites. Mica is the mineral most commonly developed in metamorphism, but locally hornblende, epidote, and garnet are abundant. Large masses of limestone were noted on the east side of Johnson Creek, and small limestone knolls are found here and there in the rolling country southeast of Conconully. The most schistose and gneissoid rocks, including small marble lenses, are those which border the granite batholith. Eastward from the granite the schistosity and metamorphism are less intense. The limestone masses of Johnson Creek and the smaller limestone knolls are crystalline, though not marmorized, and still retain their light-blue color. Closely associated with this sedimentary series are dike rocks and lavas that have undergone the same metamorphism and are probably of the same age.

AGE.

This series, because of its lithologic resemblance to rocks in near-by areas to the north and east to whose age there is some clue, is correlated with the Cache Creek formation of Dawson,¹ which is supposed to be of Carboniferous age.

STRUCTURE.

Owing to the intense metamorphism and deformation of the sediments, no well-defined structure can be recognized, nor can the thickness of the series be estimated. On Ruby Hill the schists strike northwest and dip steeply northeast; near Conconully they strike in different directions but generally dip west; at the north end of the area they strike northeast and are vertical or dip steeply southeast. On the Dorian claims, 2 miles east of Ruby, the schists and quartzites strike generally northwest and are vertical. The bedding planes in the limestone are generally obscure and the attitude of these rocks was not determined, although they appear to occur higher in the stratigraphic series than the rocks to the west. No large faults were recognized in the district, although their detection would prove difficult in the schists. Small faults which displace some of the veins along the granite contact were noted, but their throw is not great. They trend nearly east, transverse to the vein system, but there has also been movement along the walls of several of the veins.

¹ Dawson, G. M., Canada Geol. Survey Ann. Rept., new ser., vol. 7, pp. 37B-49B, 1894.

IGNEOUS ROCKS.

YOUNGER INTRUSIVES.

SIMILKAMEEN BATHOLITH.

The batholith which composes the Okanogan Mountains west of Conconully is probably part of the intrusion called by Daly¹ the Similkameen batholith and noted by Smith² and Umpleby³ along Similkameen River near Nighthawk.

Age.—The age of the Similkameen granite has not been definitely determined, but Daly considers it to be of early Tertiary age, and Umpleby, on the evidence of erosion cycles, as previously stated, considers it pre-Tertiary or late Mesozoic. It is certainly older than the Tertiary lake beds, assigned to the Miocene period, which occur in Similkameen valley near Oroville, for both Smith and Umpleby say that these beds are in part composed of granite fragments in an arkose matrix. In the Conconully and Ruby districts there is little evidence on which to determine the age.

Contact.—The contact of the granite with the metamorphic rocks was traced in an undulating north-and-south line for 10 miles from Ruby Hill to a point 2 miles north of Conconully.

Character.—The rock presents different aspects, but the most common variety is a medium-grained gray biotite-hornblende granite. In places it is coarse grained and over a considerable area shows a phenocrystic development of feldspar. Of the ferromagnesian minerals biotite is more abundant and more widely distributed. In places the hornblende is absent or is present in small amounts.

Petrography.—The granite differs in appearance and composition from place to place. Where it is cut by the tunnel of the Washington Consolidated Mines & Reduction Co., 1 mile north of Conconully, it is a gray, medium-grained rock composed of hornblende, quartz, feldspars, and biotite. The feldspars are orthoclase and more abundant calcic plagioclases, ranging from andesine to labradorite. The rock at this point, which is near the contact, can probably be classed as a quartz diorite. Westward from this point toward the summit of Mineral Hill there is a gradual transition to a medium-grained biotite granite. At the northwest end of Peacock Mountain, along an old road, the biotite granite is porphyritic in texture and contains large feldspar phenocrysts. On Ruby Hill, also near the contact with the schists to the east, the rock is essentially a biotite granite composed of quartz, orthoclase, oligoclase, and an inter-

¹ Daly, R. A., The Okanogan composite batholith of the Cascade Mountain system: Geol. Soc. America Bull., vol. 17, p. 334, 1906.

² Smith, G. O., and Calkins, F. C., A geological reconnaissance across the Cascade Range near the forty-ninth parallel: U. S. Geol. Survey Bull. 235, pp. 32–33 and 47, 1904.

³ Umpleby, J. B., Geology and ore deposits of the Oroville-Nighthawk mining district: Washington Geol. Survey Bull. 5, p. 69, 1911.

growth of quartz and feldspar; biotite is the principal ferromagnesian mineral.

OTHER INTRUSIVES.

Other areas of intrusive igneous rocks, of considerable extent but not mapped, occur at the north end of the Conconully district. Goat Mountain or Old Baldy, east of Blue Lake, is composed chiefly of a dark granitic rock closely allied to the large batholithic mass to the west. This rock is made up of orthoclase, green hornblende, andesine, microcline, quartz, and accessory titanite and apatite. It is classed as granodiorite or quartz diorite. Between the forks of Sinlahekin Creek and south of the south fork is an altered green porphyry containing quartz phenocrysts. The extent of this intrusion was not determined.

DIKE ROCKS.

Dike rocks are abundant in these districts and are particularly numerous along the contact of the batholith with the metamorphic rocks. In the schists and gneisses of Ruby Hill and Peacock Mountain granite, diorite, pegmatite, and aplite dikes and irregular masses are numerous and similar intrusives occur in the schists north of Conconully. The dikes are not confined to the schistose rocks but occur in the granite also, and several were noted that were intruded into the fissures in which veins were deposited. These dikes probably represent the most recent stage of igneous activity in the district. Pegmatites and small basic dikes are most abundant in the granite, though a pegmatite dike inclosed in schist on the steep mountain slope east of the old Ruby town site is approximately 100 feet wide. Near the summit of Mineral Hill there is a pegmatite dike that contains molybdenite. In the upper tunnel of the Washington Consolidated Mines & Reduction Co. there is a small, dark dike rich in biotite which is probably the rock known as minette, and in a tunnel near Salmon Creek a similar dike is intruded in a fissure that contains a quartz vein. In the workings of the Q. S. Copper Co. there are altered dike rocks that are closely allied to diorite in composition.

OLDER IGNEOUS ROCKS.

The older igneous rocks are those previously mentioned as associated with the sediments and regionally metamorphosed with them. The composition and texture of these rocks, which are due to the metamorphism, have therefore been greatly changed. The dark-colored dike and flow rocks, which originally were probably diabase and basalt, are generalized under the term "greenstones." A schistose porphyritic rock several hundred feet wide is intruded in metamorphosed clay shales on both sides of Sinlahekin Creek at the

northern end of the district. This rock is a reddish-brown schist spotted with white nodules. Under the microscope the groundmass is seen to be composed of shreds of brown mica and quartz granules which inclose rounded phenocrysts of a zonal plagioclase, tests of which show its composition to be that of labradorite.

In addition to these rocks, there are gneissoid dike rocks on Ruby Hill and Peacock Mountain, along the contact of the granite with the metamorphic rocks which, notwithstanding their structure, may have originated from the granite, and the secondary structure may have been produced by movements due to shrinking on the borders of the batholith as the interior of the mass cooled. The composition of these rocks is that of granodiorite or quartz diorite.

ORE DEPOSITS.

CLASSIFICATION AND DISTRIBUTION.

The ore deposits are principally of two types, quartz veins and disseminated or replacement deposits. In addition there is an isolated occurrence of a molybdenite-bearing pegmatite. The quartz veins are generally distributed throughout the area, but those most abundantly developed and of proved value are grouped in a north-south zone along the contact of granite with schist and gneiss from Ruby Hill to a point approximately 2 miles north of Conconully. The replacement deposits occur principally in a small area at the northern end of the Conconully district. The quartz veins are valuable for their silver-lead content, and the production of the district has been from deposits of this type. The replacement deposits contain small amounts of copper and gold, but as yet no ore has been produced from these sources on a commercial scale.

QUARTZ VEINS.

Occurrence.—The veins on Ruby Hill occur in the schists or at the contact of the schist and granite; those on Peacock Mountain have similar relations for the most part, except a few small veins in the granite. The veins near Conconully, however, are found in a zone $2\frac{1}{2}$ miles wide, and the westernmost ones occur 2 miles from the contact and are abundantly developed along the contact both in the granite and in the schists.

The general trend of the quartz veins follows the contact of the granite and schists, and the veins commonly conform to the structure of the wall rocks, but in places they cut the schists and dip both to the east and to the west. Most of the veins near Ruby dip to the east, but those north of Conconully dip to the west. The veins range from mere stringers to those 30 or 40 feet wide. In general, they can not be continually traced on the surface for any

considerable distance, in part because of the extensive mantle of soil on the more gentle hill slopes. Some of the mine workings expose veins for 600 feet or more and probably in some of the old workings now inaccessible still greater lengths were exposed. Elsewhere the veins form lenses that may pinch out abruptly in the fissure that contains them. The vertical extent of the veins has not been proved, owing to the little development in the district. They are believed, however, to be persistent, for a range of elevation of 2,500 feet is shown by the veins exposed near the level of Salmon Creek and those which outcrop near the summit of Mineral Hill. Erosion has removed parts of the veins, and those exposed at the lower elevations near the borders of the batholith have probably had several thousand feet removed. The minerals now found in them at the lower elevations represent deposition in the central or lower parts of the veins, whereas those at the higher elevations represent deposition in the upper parts.

Mineralogy.—The ore minerals deposited in the veins are galena, pyrite, sphalerite, chalcopyrite, and tetrahedrite, or gray copper ore, associated with quartz gangue and, in a few places, with calcite in addition. The minerals differ from place to place in the vein and from one part of the area to another; galena, sphalerite, chalcopyrite, or tetrahedrite may predominate at different places in the vein, but pyrite is nearly everywhere present. On Ruby Hill and near the summit of Mineral Hill tetrahedrite is abundant, whereas veins in the schist north of Conconully contain little tetrahedrite but abundant galena and sphalerite. These occurrences suggest that tetrahedrite was deposited above the other minerals of the veins. Chalcopyrite is an abundant constituent in places in the Arlington vein. In general, however, galena is the most abundant mineral in the districts, and sphalerite is probably in excess of chalcopyrite and tetrahedrite.

A study of the ores from Mineral Hill and north of Conconully, where there has been no movement in the veins subsequent to the mineral deposition, shows a contemporaneous development of the minerals in granular quartz. Some of the veins show successive enlargements in places where small fragments of the wall rocks and black streaks parallel to the walls represent former walls of the vein inclosed by the vein quartz. On Ruby Hill the veins have undergone extensive postmineral fracturing, and whatever may have been the conditions of the original mineral deposition chalcopyrite and tetrahedrite are now in part deposited in fine seams in the brecciated vein matter and apparently replace the quartz to a slight extent. The association of vein minerals indicates, according to extensive studies on the subject, that they were deposited under moderate conditions of temperature and pressure.

Ore shoots.—The ore minerals have a sporadic occurrence in the veins. On Ruby Hill a vein showing barren white quartz at the outcrop contains shipping ore at a depth of 100 feet. In places the quartz for a width of 10 feet or more is practically barren of ore, but elsewhere the ore occurs along the foot or hanging wall, or in narrow parts of the vein it may be equally distributed across the width. Ore shoots from 100 to 300 feet long have been developed in some of the veins, but as far as the writer is aware their extent in depth has not been determined. The shipping ore of the Arlington mine has a gross value of \$30 to \$40 a ton, and smelter payment on a small shipment from the Key mine was approximately \$37 a ton. The valuable metals of the Key ore were silver, 55½ ounces to the ton, and lead, 12½ per cent.

Oxidation and enrichment.—Oxidation has affected the veins to only a slight extent; the primary vein minerals extend to a point a few feet below the surface. Extensive downward enrichment, therefore, is not to be expected. The reports by the first State geologist mention the rich silver ores of the Ruby district and the occurrence of pyrrargyrite (ruby silver), argentite (silver glance), and cerargyrite (horn silver), but none of these minerals were noted in the ore from the present development work, and they were probably secondary minerals formed by the oxidation of tetrahedrite and redeposited at shallow depths.

Age.—The distribution, occurrence, and mineral composition of the veins in the north-south zone, along the contact of the granite and schist, all lead to the conclusion that they owe their origin to the granite intrusion. The age of these veins consequently should be very nearly that of the granite, and they are therefore late Cretaceous or early Tertiary.

MOLYBDENUM-BEARING DIKE.

A pegmatite dike containing molybdenite crops out on Mineral Hill and in part has been explored by the upper tunnel of the Washington Consolidated Mines & Reduction Co. The dike or vein trends nearly north, and is about 100 feet wide where cut by the tunnel, and it is said can be traced on the surface for nearly 4,000 feet. The dike differs in character from place to place. Quartz in places is the chief mineral, in other places cellular quartz contains much sericite in fine druses, and in still others the rock is a coarse granite in which the feldspars are unaltered. The molybdenite occurs in this rock in thin flakes and radial nodules about a quarter of an inch in diameter. It is more abundant in association with quartz and sericite, but was also noted in the less altered granite or pegmatite. Its occurrence in the pegmatite is sporadic and nowhere is it abundant enough to mine.

DEPOSITS FORMED BY IMPREGNATION AND DISSEMINATION.

Occurrence.—Deposits formed by impregnation and dissemination were noted at the northern end of the Conconully district and on the Dorian claims 2 miles east of Ruby. The mineralization near Goat Mountain consists of pyritic impregnations and disseminations in metamorphosed shales and associated dark igneous rocks that were intruded by later diorite dikes, which are probably offshoots from the Goat Mountain intrusive mass. The deposits are of low grade and contain copper and gold, chalcopyrite being the chief copper-bearing mineral. No shipments of ore have been made from these deposits, and most of the development work on them is superficial.

Age.—The age of these ore deposits is uncertain, and there is also some doubt as to the agencies which caused the mineral deposition. The proximity of some of these deposits to the Goat Mountain intrusive mass suggests there a genetic relationship, but, on the other hand, disseminated copper minerals may have been derived from the older dike and flow rocks associated with the supposed Carboniferous sediments. The pyritic replacements are also believed to have taken place during the general metamorphism of the region before the granitic intrusions.

METALLURGIC INVESTIGATIONS.

The development of these districts has been greatly hampered by the unsuccessful attempts to concentrate the low-grade vein ores. Recently Prof. Francis A. Thomson, of the State College of Washington, has conducted laboratory tests on the treatment of these ores, and the following data are taken from his preliminary report:

Assay of ores from Conconully and Ruby districts, Wash.

Sample No.	Source.	Gold.	Silver.	Copper.	Lead.
		Ounce.	Ounces.	Per cent.	Per cent.
1	Hargrove (Key mine).....	0.04	26.1	1.55	3.70
2	Arlington, 450-foot level.....	.035	58.9	1.52	2.05
3	Columbia vein.....	.03	20.1	1.43	4.00
4	Tough Nut.....	.03	23.8	1.67	(a)

a Not determined.

The minerals of sample No. 1 were carefully segregated and each segregate was assayed for gold and silver, thus indicating the minerals that carried the precious metals. The results are given in the following table:

Assay of segregated minerals of sample No. 1.

Mineral.	Gold.	Silver.
	<i>Ounce.</i>	<i>Ounces.</i>
Quartz.....	None.	None.
Pyrite.....	0.02	26.4
Sphalerite.....	None.	29.5
Galena.....	.16	71.1
Tetrahedrite.....	.12	347.6

From this test it is evident that the gold is carried almost entirely by the galena and the gray copper. In the main this is true also of the silver, but the gray copper, as one would anticipate, is the chief silver carrier.

TREATMENT OF THE ORES.

Two methods of treatment suggest themselves as probably suited to an ore of this character—leaching for ultimate extraction and concentration with the object of producing a high-grade product.

Leaching tests.—As would be expected, cyanidation of the raw ore proved impracticable, less than 50 per cent of the precious metals being extracted with excessive consumption of cyanide. Preliminary treatment of the ore with a solution of caustic alkali and metallic aluminum, as practiced on the complex silver ores of Cobalt, Ontario, gave little or no help.

Chloridizing and roasting the ore, followed by cyaniding, resulted in a total extraction of approximately 65 per cent of the valuable constituents, the loss being 15 per cent in roasting and 20 per cent in the tailing.

Oxidizing the sulphides to sulphates by roasting and then washing the ore with water to remove copper sulphate proved entirely unsuitable as a means of preparation for recovery of silver by cyanidation.

Light chloridizing and roasting the ore for 30 minutes, then washing it with water and cyaniding resulted in a total extraction of 88 per cent, the losses being 7 per cent in-roasting and 5 per cent in cyaniding. The extraction of copper by leaching with water in this experiment was above 80 per cent.

Oxychloridizing and roasting the ore, then washing it with water, followed by leaching with a solution of sodium hyposulphite (thio-sulphate), resulted in the extraction of approximately 70 per cent of the silver. The extraction of copper by leaching with water was similar to that obtained in the preceding experiment.

Concentration tests.—Concentration by treating each screen size of the sample in a glass sorting column yielded an extraction of 70 per cent with a ratio of concentration of 10 to 1. The tailing from

this treatment, when crushed to pass 150-mesh screen and cyanided, yielded a further extraction of 18 per cent of the original amount, making the total extraction by combined concentration and cyanidation 88 per cent.

Concentration on a small Wilfley table, all ore crushed to pass 40-mesh screen, yielded an extraction of 80 per cent, the ratio of concentration being 4 to 1.

Concentration on a small Wilfley table aided by flotation gave the following results: All ore was crushed to 40-mesh size, and material coarser than 100-mesh was sent to the Wilfley table. This treatment yielded an extraction of 80 per cent, the ratio of concentration being $4\frac{1}{2}$ to 1. Material finer than 100-mesh size was sent to a froth flotation machine using eucalyptus oil in acid solution, and this treatment yielded an extraction of 73 per cent and a ratio of concentration of $3\frac{1}{2}$ to 1.

Concentration by flotation alone after crushing ore to pass an 80-mesh screen, eucalyptus oil and wood creosote being used in a non-acid solution, yielded an extraction of 91 per cent silver and 95 per cent copper. The ratio of concentration was about $2\frac{1}{2}$ to 1.

CONCLUSIONS.

Although this investigation has not yet been carried far enough to justify final conclusions or specific recommendations, it is evident that local treatment can be made to yield satisfactory results.

The choice at present appears to lie between (1) the light chloridizing and roasting of the ore, followed by cyaniding after washing it with water, and (2) the flotation concentration of the entire ore after crushing to 80-mesh. Each of these methods by laboratory test shows an extraction of approximately 90 per cent of the silver and a large proportion of the copper. The flotation method, of course, yields a concentrate which must be either shipped to a smelter or treated further at the mine. It seems probable that an application of the light chloridizing and roasting, washing with water, and cyaniding, which has proved successful with the ore, might be applied to the flotation concentrate with equal or greater success. This point will shortly be investigated.

Credit for most of the detailed laboratory work in these investigations should be given to Mr. Henry E. Doelle and for much of the analytical work to Mr. Edgar H. Schuneman.

FUTURE OF THE DISTRICTS.

The future of these districts as a whole will depend largely on the development of ore reserves and economical mill treatment. With regard to ore reserves, several of the properties have ore

shoots of milling grade from 100 to 300 feet long, but their vertical extent has not been determined in any of the workings now accessible, though in the Arlington mine good ore is disclosed 450 feet below the vein outcrop. Most of the properties have directed their development along the strike of the veins rather than on the dip. Though ore shoots of considerable extent will probably be developed, the variability of metal content in the shoots must be considered, and the ore bodies should be explored at several points before the erection of elaborate mill equipment is undertaken. The experiments by Prof. Thomson indicate that successful mill treatment will be accomplished.

MINES AND PROSPECTS.

KEY MINE.

The Key mine (1)¹ is located three-quarters of a mile north of Conconully, on the east side of Salmon Creek, at an elevation of 2,500 feet. The property is developed by a tunnel 300 feet long, a shaft 45 feet deep, and a drift 105 feet long. The tunnel and drift follow the vein, which trends N. 25° E. and dips about 60° W. The wall rocks are granite and mica schists; some of the schists are metamorphosed igneous rocks. The vein is 3 to 10 feet wide and contains some ore minerals as far as developed by the tunnel. Galena, pyrite, chalcopyrite, and a little sphalerite occur in the ore, in places in sufficient abundance to make a low-grade shipping ore, and much of the vein is of concentrating grade. In 1914 a shipment of 12 tons was made to the smelter at Trail, British Columbia, and payment for the silver and lead content was made at the rate of \$37 a ton.

TOUGH NUT.

The Tough Nut (2) was discovered in 1886 and is located on the same vein as the Key. It is developed by a tunnel the portal of which is 1,100 feet north from the Key shaft. The workings were not accessible, but the tunnel is said to be 250 feet long and a winze 40 feet deep is sunk on the vein. The vein is 3 to 10 feet wide and the wall rock is a sandy-textured quartz-mica schist that strikes N. 25° W. and dips 60° W. Between the Tough Nut and the Key there are small granite dikes in the schist. About 40 tons of ore lie on the dump, and galena, pyrite, chalcopyrite, and sphalerite were noted. No recent ore shipments have been made from this property.

¹The mines and prospects are numbered to correspond with their locations indicated on pl. 1.

SALMON RIVER CHIEF.

The Salmon River Chief (3) is a patented claim that lies a short distance southeast of the Tough Nut. The property is developed by a crosscut tunnel 150 feet long to its intersection with the vein and drifts to north and south of approximately 250 feet in each direction. The vein trends N. 35° W. and dips 35°–60° SW. It is inclosed in sandy mica schists, and its attitude corresponds to that of the schists. The schists are foliated in places and contain small stringers of aplite and pegmatite. The vein is 4 feet wide at one place, but near the end of the north drift it pinches out and in the south drift is but 8 inches wide. There has been considerable post-mineral movement along the fissure, and in places gouge material several inches thick is composed of ground-up minerals of the vein. The minerals are galena, sphalerite, chalcopyrite, and pyrite contained in a massive white quartz. The tenor of the ore was not learned, although it appears to be equal to that of the other veins near by.

COPPER KING.

The Copper King claim (4) adjoins the Salmon River Chief to the northwest, and the development work on both properties is probably on the same vein. Two drifts 100 feet and 50 feet long, on the north and south sides, respectively, of a small gulch, comprise the development work on this claim. The vein is about 7 feet wide, trends N. 40° W. and dips 55° SW. At the surface the quartz is honey-combed, but at depths of a few feet sulphides appear in a mineralized zone 3 feet wide. The ore minerals are galena, sphalerite, chalcopyrite, and pyrite, and the value of the ore in silver, lead, and copper is said to be \$38 a ton.

ESTHER.

Northeast of the Copper King tunnel and 180 feet higher is the Esther claim (5). This claim is developed by a tunnel 74 feet long, which follows a north-south quartz vein from 1 to 3 feet wide that dips 70° W. The vein cuts fine-grained mica schists at a small angle and contains a rather sparse mineralization of galena, sphalerite, pyrite, and chalcopyrite.

HOMESTAKE.

The Homestake (6) is a patented claim near the Salmon River Chief. The tunnel which developed the property is now caved, and no work has been done for many years. No ore has been shipped from the property, but it is said that attempts to concentrate the ore

in an old mill on Salmon Creek proved failures. The country rocks are schists and small granitic intrusives.

MONITOR.

The Monitor property (7), located north of the Key mine, is developed by a tunnel 200 feet long, driven N. 20° E. along a fissure which for most of its course contains a quartz vein that dips 70° W. The quartz vein has an average width of 2 feet and is contained in contorted schists. At the face the vein is apparently faulted out. The mineralization consists of a rather scanty deposition of sphalerite and chalcopyrite, with more abundant pyrite.

STAR.

The Star (8) is a patented claim that lies west of Salmon Creek and north of the Washington Consolidated Mines & Reduction Co.'s group. The mine has not been worked for many years, but it is reported that in 1913 a carload of ore was sorted and shipped from the dump. The development is directed along a quartz vein, which has apparently been displaced 50 feet or more by an easterly fault. An incline shaft No. 1, now filled with water to the tunnel level, 90 feet below the collar, is sunk on the northern part of the vein. The tunnel starts from a point near the west bank of the creek and comprises a crosscut of 125 feet to the vein and a drift south of 290 feet. The vein ranges from 18 inches in width at the north end of the drift to 3 feet at the shaft and dips at an average of 45° W. South of the shaft the vein and wall rocks are greatly sheared, and the vein is faulted out near the face of the drift. The wall rocks are sericitized granite. Some ore has been stoped for a distance of 50 feet north of the shaft and several feet above the tunnel level. Incline No. 2, about 150 feet southwest of No. 1 and 50 feet higher, is sunk on a quartz vein 10 feet wide, which is evidently the faulted continuation of the vein to the north. A cross-cut tunnel, about 150 feet southeast of incline No. 1 and 50 feet lower, is driven west 185 feet and intersects the quartz vein of incline No. 2. The vein trends N. 5° E. and dips 50° W., as shown by drifts to the north and south, 50 feet each way. The vein is crushed and stained with copper, but contains a rather sparse primary mineralization of pyrite and chalcopyrite.

WASHINGTON CONSOLIDATED MINES & REDUCTION CO.

The Washington Consolidated Mines & Reduction Co. (9) owns numerous claims, some of which are patented, that extend from Salmon Creek westward nearly to the summit of Mineral Hill. The claims are developed principally by two tunnels, one on the west

bank of Salmon Creek at an elevation of 2,300 feet and the other on Mineral Hill at an elevation of 3,700 feet. The lower tunnel is driven westward to intersect the numerous veins that outcrop on Mineral Hill between the two tunnels. It is reported that at least 30 veins have been found between these points. The lower tunnel is now 800 feet long, and work was being done at the time of the examination, but the progress of the tunnel, which is driven through hard granite by hand drills, is necessarily slow. Two veins have already been intersected by this tunnel, one 11 feet wide 88 feet from the portal and another of equal width 380 feet from the portal. The first vein strikes N. 5° W. and dips 46° W.; the second vein has a parallel strike, but dips more steeply to the west than the first. Drifts have been driven to the north and south along the second vein, each 100 feet long. At the face in the north drift the vein is about 5 feet wide. There has been considerable movement along this vein, and gouge on the walls contains much comminuted sulphide mineral. The ore is a mixture of galena, sphalerite, pyrite, and chalcopryite, deposited contemporaneously in the fissure with granular white quartz. The ore observed in the second vein occurs principally along the hanging wall or from the center of the vein to the hanging wall. Between the upper and lower tunnels granite is the dominant rock.

The upper tunnel (10) of the Washington Consolidated Mines & Reduction Co. contains over 2,000 feet of development and 400 feet from its portal connects with an inclined shaft from the surface. From the portal to the shaft and 600 feet beyond the drift is in the Columbia vein, which trends N. 10° E. and dips 60° E. The vein is 6 inches to 3 feet wide and contains galena, pyrite, sphalerite, chalcopryite, and gray copper. From the shaft the tunnel continues to the northwest and intersects several small veins, one of which, the Frankie Boy, contains high-grade silver ore. This vein trends N. 25° E., dips 60° W., and its average width is 1 foot. The ore is an intergrowth of granular quartz, galena, tetrahedrite, pyrite, and chalcopryite. The granite wall rocks are bleached and contain much secondary mica, or sericite. Beyond the Frankie Boy vein the cross-cut tunnel intersects and follows for a distance the molybdenite-bearing pegmatite dike described on page 21.

LEUENA.

The Leuena claim (11) is located on Mineral Hill northwest of the upper tunnel of the Washington Consolidated Mines & Reduction Co. at an elevation of 4,600 feet. The property is one of the first discovered in the district, but no work has been done for many years. Two shallow shafts and a short tunnel were inaccessible.

The vein apparently trends N. 55° E. and dips vertically. It is reported that several carloads of high-grade silver ore containing much tetrahedrite were shipped from this property to a San Francisco smelter.

LADY OF THE LAKE.

The Lady of the Lake prospect (12) is located about half a mile northeast of Conconully and a short distance above Conconully Lake. A vein 3 feet wide, which trends N. 10° E. and dips 45° W., inclosed in schist and sheared dike rocks, is explored by a tunnel 125 feet long. The vein at the face of the tunnel is faulted in blocks with small offsets. The vein matter is granular white quartz and calcite, which contains bands of good ore consisting of pyrite, galena, chalcopyrite, and a little sphalerite, but the ore as a whole is low grade. The deposition of gangue and metallic minerals is apparently contemporaneous. The occurrence of calcite is unusual in the veins of the district.

Other prospects are located north and west of Conconully, but information regarding their names was not obtained. Most of them are located on veins that have been previously described.

PEACOCK MINING & MILLING CO. CLAIMS.

The Peacock Mining & Milling Co. controls 33 claims (13) including two mills sites, which occupy the greater part of the easterly slopes of Peacock Mountain, extending to Salmon Creek. At the time of the writer's examination these claims were being surveyed for patent. At the southern end of this group are some old shafts and tunnels on the Nevada, Wyoming, and Kansas claims, work on which has been suspended for many years, and only parts of the Nevada workings were accessible. The company is now engaged in driving a large cross-cut tunnel westward from the west bank of Salmon Creek to intersect the veins of the group; this tunnel will attain a depth of approximately 2,000 feet below the surface of the westernmost vein, which outcrops on the Republic and Marguerite claims. The tunnel has been driven about 700 feet of the total estimated distance of 2,100 feet to intersect the westernmost vein. The principal rock of this tunnel is a gneissoid granodiorite or quartz diorite. Schists intruded by pegmatite and aplite dikes outcrop above the tunnel and extend westward to an elevation of 4,200 feet, beyond which is the granite. Several veins are exposed on this group, but apparently the largest and most persistent are those near the contact of the granite and schists, on which the early development work was done. In a recent communication Mr. G. H. Wheeler, of Conconully, reports that in December, 1915, a vein was cut 709 feet

from the portal of the crosscut tunnel. The vein or shear zone was not observed on the surface, but in the tunnel it strikes about north, dips 30° W., and is 6 feet wide. A sample of ore from this vein, sent by Mr. Wheeler, is chiefly massive pyrrhotite and quartz, but no assays have been made. This is the only occurrence of pyrrhotite reported or observed in these districts. The mineral is characteristic of deep-seated deposits.

The Nevada claim (14) is developed by a shaft 216 feet deep which connects with tunnel No. 2, 1,300 feet long, and from which drifts are opened on the 40 and 100 foot levels. The vein on the surface is composed of iron-stained vesicular quartz about 8 feet wide; it trends N. 20° W. and dips 65° E. The footwall is mainly granite and the hanging wall schist and gneiss. On the 40-foot level a drift extends 50 feet south of the shaft. The vein here is 6 feet wide, and the best ore streaks have a maximum width of 1 foot on the walls. On the 100-foot level a drift extends 50 feet south and 120 feet north of the shaft. In the south drift the vein is 6 feet wide near the shaft but narrows near the south end, where several slip planes that cut the vein at a slight angle have ground up the vein to a brittle aggregate of quartz and vein minerals that contains inclusions of schist and granite wall rocks. In the north drift 30 feet from the shaft the vein is cut off by a fault, which trends N. 70° W. and dips 60° S. Exploration to find the continuation of the vein has apparently been successful in a crosscut driven westward on the footwall side of the fault, where with an approximate displacement of 30 feet the vein is inclosed by sheared and sericitized granite. In the tunnel level at the bottom of the shaft the vein is cut off about 25 feet south of the shaft by the fault noted on the 100-foot level. South of this fault the vein to the caved part of the tunnel about 100 feet distant is from 10 to 15 feet wide, but to the north the continuation of the vein has not been found, for the prospecting work has been poorly advised, as the drift to the west, which logically would cut the vein in the footwall, has been driven in the hanging-wall side of the fault. The vein on this level is composed of a massive white quartz, rather sparsely mineralized along the walls. The ore is a mixture of quartz, galena, pyrite, chalcopyrite, sphalerite, and probably a little tetrahedrite. It is essentially a milling ore, and it is reported that two samples of the ore from the drift in the shaft and from the face of the vein at the bottom of the shaft, presumably from enriched parts, assayed as follows: Copper, 0.5 and 0.8 per cent; lead, 18 and 2.2 per cent; and silver, 19.2 and 10.4 ounces to the ton. According to Mr. McDaniel, of Conconully, a carload of ore shipped 15 years ago to a smelter netted \$10 a ton in silver and lead, the assay value of the ore being about \$27 a ton.

Near the summit of the east ridge of Peacock Mountain, at an elevation of 4,050 feet, an old shaft on the Republic claim is sunk on a quartz vein 2 feet wide that strikes N. 20° W. and dips 70° E. The vein is near the granite contact and the wall rocks on the east are schist and sheared dike rocks. The vein is mineralized with pyrite and galena and stained with copper salts. North of the shaft, on the ridge, the vein at one place is 20 feet wide, but in a short distance narrows to a few feet. The vein at the outcrop is composed of honeycombed quartz slightly copper stained. On the Blue Grouse claim of this group a shallow tunnel in schist and gneiss cuts vein material of sheared quartz and country rock 10 feet wide, which trends N. 20° E. and dips 70° E. The vein contains sparse galena and is stained with copper but can be traced only a short distance.

BUCKHORN GROUP.

The Buckhorn group (15) of several claims lies west of Salmon Creek and adjoins on the east the south end of the Peacock group. A tunnel 175 feet long penetrates highly contorted schist and dikes of aplite and pegmatite. A shear zone 40 feet from the face contains black gouge and bunches of white quartz, but no metallic minerals were noted.

PLANT-CALLAHAN GROUP.

The Plant-Callahan group (16) consists of several claims on the steep hillside east of Ruby. The property is one of the first discovered in the district, and it is reported that in 1886 a small shipment of rich silver ore from the surface yielded \$6,000, but no shipments have been made since. The development consists of a tunnel 65 feet long that connects with a shallow shaft, open cuts, and a lower tunnel 175 feet long, which is 500 feet below the upper workings on the vein outcrop. In the upper tunnel the mineralization occurs in a shear zone in fine-grained biotite schists and consists of stringers and bunches of quartz which range from mere seams to masses several feet wide. One stringer about 2 feet wide trends N. 45° W. and dips steeply northeast. It contained much tetrahedrite, and selected samples yielded over \$1,000 a ton in silver. A pegmatite dike 100 feet wide outcrops between the upper and lower tunnels.

FIRST THOUGHT.

The First Thought mine (17) is mentioned in the report of the first State geologist of Washington as being one of the first discoveries of the district. It is reported by Mr. McDaniel, of Conconully, to have produced ore valued at \$66,000 and was worked continuously for a period of five or six months. Its production, which

was concentrated in a mill on Salmon Creek, was 40 tons a day. The property is developed by three long tunnels, all of which are flooded because of caving near each portal. The vertical distance between the upper and lower tunnel probably does not exceed 200 feet. Above the upper tunnel some open cuts expose a quartz vein 10 feet or more wide that trends N. 10° E and dips 60° E. The wall rocks are gneiss and schist.

LAST CHANCE.

The Last Chance (18) is located at the north end of Ruby Hill at an elevation of 3,500 feet. The property is developed by a shaft that is reported to be 400 feet deep and by a tunnel that is accessible only for 400 feet. The workings have been abandoned for many years, and the shaft contains water to the tunnel level. The tunnel follows the vein, which, near the portal, trends N. 50° W. and dips 50° W., but toward the caved part of the drift is overturned and dips 60° E. The vein in places is greatly crushed and displaced by several easterly slips. The ore consists of galena, pyrite, chalcopyrite, and sphalerite, with a little tetrahedrite, and has generally been crushed. At the shaft the ore is 4 feet wide, but the shoot gradually narrows and pinches out 200 feet southeast of the shaft. Beyond this point to the caved part of the drift, 200 feet farther, the fissure is occupied by a pure quartz vein from 8 to 12 feet wide. The vein occurs at the contact, with granite on the west and schist and gneiss on the east wall. No shipments of ore are reported from this mine, although the ore on the tunnel level is apparently of good concentrating grade.

FOURTH OF JULY.

The Fourth of July property (19) lies about half a mile north of the Arlington mine at an elevation of 4,500 feet. An old shaft is on the property, but the workings have long been abandoned and little information regarding them could be obtained. The first State geologist of Washington says in his first annual report that the vein is 10 feet wide and contains a pay streak 18 to 24 inches wide. The ore had a high silver content, and several shipments were reported, the total production being \$36,000. The vein is probably the continuation of the Arlington fissure, as it is in alignment with that fissure and occurs in schist near the contact with granite.

ARLINGTON MINE.

The Arlington group (20) consists of 10 patented and several unpatented claims on the crest of Ruby Hill. The old shaft of the Arlington mine is located on the west slope of Ruby Hill about 200

feet below its summit. The vein is one of the first discoveries of the Ruby district. Two years ago the mine was reopened after a long period of inactivity. Prior to 1901 the returns on 1,000 tons of ore are reported¹ to have been \$25,000. Since October, 1914, 15 carloads of ore containing 583.44 tons were shipped, from which the net returns were \$17,021.71, or about \$29 a ton. The average content of metals in this shipment paid for by the smelter was as follows: Gold, 0.025 ounce to the ton; silver, 75.96 ounces to the ton; and copper, 1.3 per cent.

The property is developed by two tunnels at levels 240 feet apart, which have a total development over 3,000 feet. The upper tunnel connects with the old shaft that is 200 feet deep and is now being reopened for an airway. The early production of the mine came from drifts from the old shaft above the upper tunnel level, but recent shipments have been made principally from stopes in the lower tunnel. Extensive improvements have recently been made at the mine. The company erected a pole line, and electric current is transmitted from the plant of the Okanogan Valley Power Co., at Okanogan, 12 miles distant. Motors have been installed to operate the compressor and station pump used in sinking a shaft on the vein from the lower tunnel. Several mine buildings were being erected during the writer's visit. The upper tunnel is driven eastward 420 feet to the first vein and the lower crosscut tunnel is 975 feet to the vein.

The outcrop of the Arlington vein on which the shaft was sunk shows iron-stained vesicular quartz several feet wide, inclosed in schists and gneisses, trending about N. 10° E. and dipping steeply east. In the upper tunnel two parallel northerly veins about 30 feet apart have been cut. The eastern vein has been explored for 350 feet along its strike and dips 60°-75° E. The vein is from 6 inches to 5 feet wide, but contains little ore. The wall rocks are greatly foliated schists, which are hydrothermally altered and show an abundant development of sericite. The western vein encountered by the upper tunnel is that on which the shaft is sunk. This vein is explored for 700 feet, but differs greatly in character at different points. Its maximum width is 10 feet, but it pinches out in the fissure near the north and south ends of the drifts. The vein, which at the collar of the shaft dips to the east, on this level is vertical or dips steeply west. Near the north end of the drift the vein is 8 to 10 feet wide and consists of pure white quartz, but toward the shaft and in the south drift it narrows and is sporadically mineralized. The wall rocks are schists, gneiss, and granite. The lower tunnel of the Arlington has encountered but one vein, which is probably

¹ Landes, Henry, Washington Geol. Survey Ann. Rept., vol. 1, p. 72, 1901.

the continuation of the westernmost one of the upper tunnel. This vein is explored for 600 feet in drifts north and south from the crosscut. It is 1 foot to 6 feet wide and is inclosed in contorted schist and granite. In the north drift the vein is displaced by an easterly fault which throws it 8 feet to the west. At the intersection of the tunnel and vein the quartz is 6 feet wide and contains ore that carries \$30 a ton in valuable metals. To the north the vein narrows to 3 feet, but the ore is of high grade and the principal mineral is tetrahedrite or gray copper.

The ore differs in different parts of the vein. In places the quartz contains abundant chalcopyrite, with galena and sphalerite in slightly smaller amounts, but in other places gray copper largely predominates. Extensive movements along the walls of the vein have resulted in a granulation of the quartz and probably a redeposition of the chalcopyrite and gray copper, as these minerals occur in thin filaments that penetrate the quartz and other metalliferous minerals of the vein. Elsewhere all the minerals occur in granular aggregates and intergrowths that indicate contemporaneous deposition. Observations at different parts of the vein show that the ore occurs in shoots. Above the upper tunnel level a considerable quantity of ore has been removed, but on that level the ore minerals are rather scattered. At the lower tunnel level an ore shoot of considerable promise is exposed.

Q. S. COPPER CO.

The Q. S. Copper Co. controls 24 claims (21) which lie on the steep mountain slope east of Blue Lake. Two crosscut tunnels 1,200 feet apart are directed to intersect the deposit, whose copper-stained outcrop is about 1,600 feet above the lower tunnel level. The upper tunnel is 1,060 feet long and is beneath the outcrop of the vein; the lower tunnel, 600 feet long, is still 2,000 feet or more from a point beneath the outcrop. The country rocks are metamorphosed dark-colored clay shales and basic igneous rocks intruded by diorite dikes. All are hard, tough rocks that are difficult to drill. In the lower tunnel a dark-greenish rock that contains feldspar phenocrysts in a groundmass of biotite and altered ferromagnesian minerals is probably an altered diorite. Some of the feldspars are near labradorite in composition. In the upper tunnel a dappled green, gray, and black schistose igneous rock is composed of biotite, epidote, quartz, and altered feldspars, together with sparsely disseminated pyrite. The metamorphosed sediments are massive clay shales in which secondary minerals, such as hornblende, epidote, and biotite, are abundantly developed. The sedimentary rocks trend about N. 45° E. and are vertical in the lower tunnel; their strike in the upper tunnel

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is N. 20° E. and their dip is also vertical. Pyrite and chalcopyrite are disseminated throughout the rocks, though generally in very small amounts. In the lower tunnel this mineralization is very sparse and nowhere abundant enough to constitute an ore. For a distance of 230 feet from the face of the upper tunnel there is a sparse mineralization in seams and disseminations of pyrite and chalcopyrite. About 40 feet of this zone is claimed by Mr. Dewey, manager of the company, to be ore with a copper content of 2½ per cent, but the deposit as a whole probably contains less than 1 per cent of copper. The ore commonly contains only traces of gold and silver, but a table of assays published by the company gives a gold content as high as \$37 a ton from surface ores.

BLUE LAKE.

The Blue Lake prospect (22) lies on the east side of the northward-trending ridge from Goat Mountain at an elevation of 3,100 feet. A tunnel driven west 300 feet in granite was the only development noted on the property, and apparently no work has been done for several years. Several small quartz stringers were seen in the tunnel section, but there is no well-defined vein, and apparently little to encourage further development. Vein material on the dump contains a little chalcopyrite.

OKANOGAN COPPER CO.

The Okanogan Copper Co. (23) has done some slight development work on a group of claims north of Sinlahekin Creek. From the creek level a tunnel has been driven north 500 feet along the contact of the Goat Mountain intrusive rock with metamorphosed massive green and blue shales, the rock being extremely hard and tough. The tunnel intersects a fault and shear zone containing much black gouge and bunches of quartz that are reported to contain small quantities of gold. Another tunnel a short distance northwest and 200 feet higher than the tunnel on the creek level is driven in massive shales which strike N. 40° E. and dip 80° SE. A shear zone 20 feet wide that is crosscut contains contorted shales and iron-stained quartz stringers or veins 1 to 3 feet wide, which lie along the walls. The quartz veins are said to contain gold. The shales contain sparsely disseminated pyrite and near the entrance of the tunnel a yellowish efflorescence with astringent taste is probably alum formed by the action of sulphate waters with the wall rocks. At an elevation of 3,000 feet a short tunnel explores massive heavily pyritized shales which are said to contain a little copper and gold, though chalcopyrite was not observed in the sulphide material.

GOLD QUARRY GROUP.

The Gold Quarry group (24), consisting of 20 claims, lies on either side of Sinlahekin Creek, west of the Okanogan Copper Co. group. The development work consists of open cuts, short tunnels, and shallow shafts. Laminated quartz-mica schists, which contain abundant hornblende and epidote, and carbonaceous schists, which contain, in addition to the other secondary minerals, numerous pink garnets, are the principal sedimentary rocks. They are associated with greenstones and a schistose feldspathic porphyry that forms a prominent band which extends east and west on the north side of Sinlahekin Creek. The metamorphosed shales are in general sparsely mineralized with pyrite along the lamination planes, but locally the mineralization is more intense and in these places the reddish-brown outcrop is exploited by the shallow workings. The pyritized shales are said to carry considerable gold, but no assays were made, and before work is continued on this property careful sampling should be done and reliable assays obtained. Enrichment of the ore bodies in depth is not probable.

DORIAN CLAIMS.

The Dorian claims (25) are in the NW. $\frac{1}{4}$ SE. $\frac{1}{4}$ sec. 34, T. 35 N., R. 25 E. Several open cuts have recently been made in a bed of fine-grained sericitic quartzite about 50 feet wide which is inclosed by sandy mica schists or grades into them. The formations strike northwest and dip from 45° SW. to vertical. The quartzite for a distance of 100 feet along its strike is of a light-green color, which is due to the deposition of small flakes of a green mineral in the bedding planes. This color was at first thought to be due to minute crystals of malachite (copper carbonate), but a chemical test of the mineral gave a large chromium content, and on microscopic examination the mineral was determined to be mariposite, a chromium mica. Near the quartzite a small prospect is opened in black quartzose schist and shale that is impregnated with pyrite, but no valuable minerals were noted.



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SOME MANGANESE MINES IN VIRGINIA AND MARYLAND

BY

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SOME MANGANESE MINES IN VIRGINIA AND MARYLAND.

By D. F. HEWETT.

INTRODUCTION.

The demand for large amounts of manganese ore arose with the development of the modern steel industry as a result of the introduction of the Bessemer and open-hearth processes of making steel during the period 1865 to 1870. To satisfy this demand the deposits of the territory easily accessible from the iron and steel producing centers of the Eastern States were actively exploited. Thus most of the deposits of Virginia, Georgia, and Arkansas that are now known were discovered and explored between 1875 and 1895. Domestic deposits have, however, failed to supply the increasing demands of the steel industry, and although in 1890 the domestic production of manganese ores was almost equal to the imports, for the five-year period 1910 to 1914 it was but 1 per cent of the imports.

Owing to the fact that Virginia appears to possess a larger number of deposits than adjacent States and to her proximity to markets, Virginia has supplied a large part of the domestic production. This part has ranged from about one-fifth during years of depression to nearly the whole, and the average proportion for the period 1880 to 1914 was 61 per cent. Nearly two-thirds of this ore is said to have come from one mine, the Crimora, in Augusta County.

The present paper is based on data collected during brief visits in the spring months of 1913, 1914, and 1915, in connection with the gathering of statistics of the production of manganese ore. Four of the mines described in this paper, with the Crimora, Evington, and a few others, have produced practically all the manganese ore mined in Virginia for the last five years. The location of the mines is shown in figure 4. From two of the mines here described, the Kendall & Flick and the Piedmont, ore has been mined more than 200 feet below the surface, which was about the greatest depth that had been attained in manganese mining in Virginia. The visits to the Niesswaner shaft of the Kendall & Flick mine were opportune, for deep work was soon afterward stopped and the shaft is now abandoned. With the exception of the Crimora deposit, which is much larger, the deep zone of the deposit at this mine has probably been more thoroughly explored than any other in Virginia.

One object in presenting this paper, in addition to describing the occurrence of the ores, is to call attention to the presence of four types of deposits, one of which has not been previously recognized

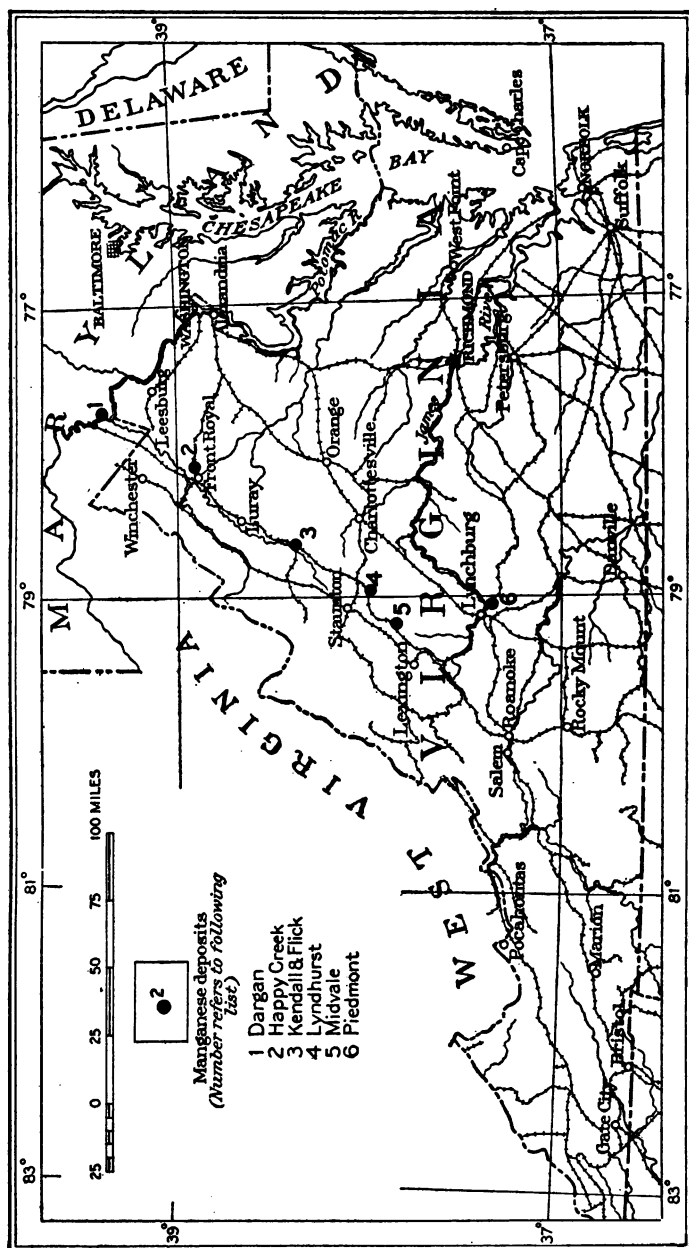


FIGURE 4.—Map showing location of manganese deposits in Virginia and Maryland.

in Virginia. These four types of deposits offer essentially the same problems in exploitation, but the chances of persistence of the manganese minerals in depth appear to be different for each type. Atten-

tion is drawn also to a possible relation of the deposits to the erosional features of the region.

The exploitation of manganese mines in Virginia appears to have been profitable only rarely when viewed over the entire period of exploration. Doubtless many factors have contributed to this result. If further investigation should tend to support the hypothesis that is here set forth, it may serve as an aid in the search for new deposits as well as the exploration of those already known.

MINERALS OF THE ORES.

The manganese minerals in the ores of this region are few in number, and belong to the group of brown to black oxides and hydrous oxides, several of which can not be positively identified without analysis. In the following description the usage of names and the identification of species are based on the table prepared by Fermor¹ as the result of considerable study in connection with the preparation of the report on the manganese deposits of India. He says:

In naming Indian specimens of manganese ores the practice I have followed with regard to the uncrystallized or amorphous ores is to designate all those as psilomelane that in any way exhibit the characters of that mineral, the hardness especially being a criterion. If the mineral be a soft one and show a finely crystalline structure, I have relegated it to pyrolusite, whilst if it shows no signs of crystalline structure nor of the compact, firm, amorphous structure of psilomelane, I have called it wad, this term being thus reserved for the indefinite mixtures so often found in manganese-ore deposits.

Psilomelane is the commonest manganese mineral in the Virginia deposits and forms more than 75 per cent of the washed ore. Its distinguishing features are its rounded or botryoidal forms, its lack of crystalline outlines, and its hardness—it can not be scratched by a steel knife. The composition is complex, and although the percentage of manganese ranges only from 50 to 57, the amounts of minor accessory ingredients, such as iron, barium, and potassium, show a wide range. The percentage of water ranges from 2.5 to 6.0.

Manganite, a hydrous oxide containing 62.4 per cent of manganese and 10.3 per cent of water, is present in most of the ores, but in many specimens it is not conspicuous. It is distinguished by its crystal forms, which are commonly needle-like, bladed, or wedge-shaped, and its degree of hardness, as it is softer than a knife blade. Compared with psilomelane, it is of simple composition, for the accessory ingredients of psilomelane are absent.

Wad includes a number of poorly defined hydrous minerals that contain a large proportion of manganese oxide and minor amounts of such accessory substances as barium oxide, iron oxide, and clay.

¹ Fermor, L. L., The manganese-ore deposits of India: Geol. Survey India Mem., vol. 37, pt. 1, pp. 117, 228-229, 1909.

It is commonly a loosely coherent brown powder not sharply defined from the clay in which it usually occurs. It contains from 30 to 42 per cent of manganese and 7 to 10 per cent of water.

Pyrolusite, which is now regarded as formed from manganite by the loss of most of the water, a change that causes a loss of coherence, has not been definitely recognized in any of the ores. Dark steel-gray powder forms irregular masses in clay at several mines, notably at Happy Creek, but tests of a number of specimens in a closed tube consistently show more water than pyrolusite. The materials are grouped with wad.

The data gathered in connection with this investigation show that the relations of the manganese minerals bear some resemblance to those noted by Fermor¹ in deposits of the Sandur Hills and Mysore, in India, in which wad is commonly present. Noting the persistent occurrence of psilomelane in masses of wad, Fermor states:

It is evident from the mode of association of these two minerals that the wad is the first-formed mineral and that it subsequently gets converted into psilomelane, probably on the advent of a further portion of manganese in solution.

Although there are here and there, as at the Piedmont mine, large masses of wad free from nodules of psilomelane, and elsewhere, as at Happy Creek, nodules of psilomelane in lenticular zones of clay with no wad, in most of the deposits the nodules of psilomelane occur in masses in wad that more or less completely replace the residual clay. It appears that psilomelane, which contains less water than wad, tends to form most readily in masses of wad. Many nodules that appear to be wholly psilomelane, however, show in a polished section alternating thin layers of psilomelane and manganite. In some nodules manganite fills sharply defined veinlets in psilomelane and is clearly later in origin. From this it appears that there is no uniform trend from the formation of the more hydrous to the less hydrous oxides of manganese. Although the chemical reactions of the process are obscure, the method of formation of nodules of manganese ore appears to be similar to that by which concretions of silica, calcium carbonate, and barium sulphate are formed.

The amorphous clays that occur in the manganese deposits show a great range in color. Locally these clays contain a large proportion of limonite, and every transitional stage to wad may be observed. Nodules of limonite, some of which are highly siliceous, are common in the surface zone at Happy Creek and have been found sporadically at Midvale and in the Niesswaner shaft, at Elkton, but limonite is generally rare on the lower levels. Sericite is sporadically present, but much of the clay adjacent to the masses of ore is free

¹ Fermor, L. L., *op. cit.*, p. 117.

from it. In addition to angular grains of quartz that are residual from the rocks in which the deposits occur, quartz occurs in several varieties that appear to have been formed during the decomposition of the bedrock. The commonest of these is a microcrystalline variety which generally occurs as thin veinlets in clay but which here and there, as in the Niesswaner shaft, forms rounded nodules as large as 2 inches in diameter. Quartz also occurs at Elkton and Happy Creek as minute doubly terminated needle-shaped crystals with numerous rounded nuclei of calcite.

NATURE OF THE DEPOSITS.

Except for a few descriptions of isolated mines, such as that of the Crimora mine by Hall,¹ the most important contributions to the knowledge of the manganese deposits of Virginia have been based upon systematic examinations of practically all the mines in operation in the State at any one time. As a result of his investigations in 1889 Penrose² reached the conclusion that the ores of the Blue Ridge region as mined represented the weathered and decomposed outcrops of persistent beds of sediments of Cambrian age which were not only much richer in manganese than the adjacent sediments but that the manganese ores occurred in the beds in essentially the same condition as they are found in the superficial mine workings. He thought that the inclosing masses of clays were derived from the decomposition of the adjacent sediments. A consequence of this view would be that the ores should be traceable over the surface in persistent belts coincident with the outcrop of the manganimiferous beds and should persist downward as far as the beds continue.

As the result of an extensive investigation covering the entire United States in 1908 Harder,³ while recognizing that in Virginia, Tennessee, and Georgia a belt of manganese deposits coincides roughly with the outcrops of a group of Cambrian shales and quartzites, concluded that the presence of the deposits is determined by an impervious stratum of underlying quartzite, but that the manganese has probably been derived from manganimiferous minerals disseminated through a thick group of beds of shale and limestone. He also concluded that the ores as mined were formed both by replacement of residual clays and by deposition in pervious channels, such as breccia and fault zones. According to this view, manganese oxide minerals would not persist deeper than the zone accessible to circulating waters of surface origin.

¹ Hall, C. E., Geological notes on the manganese ore deposits of Crimora, Va.: *Am. Inst. Min. Eng. Trans.*, vol. 20, p. 46, 1892.

² Penrose, R. A. F., Manganese, its uses, ores and deposits: *Arkansas Geol. Survey Ann. Rept.* for 1890, vol. 1, p. 385, 1891.

³ Harder, E. C., Manganese deposits of the United States: *U. S. Geol. Survey Bull.* 427, p. 99, 1910.

The following description recognizes four types of replacement deposits—(1) in residual clay, (2) in the clay of a fault zone, (3) along pervious zones in schistose rocks, and (4) in channel sediments. Each of these types except the last was recognized by Harder.

1. Replacement masses in residual clay are well shown in the deposit near Elkton, Va., explored through the Niesswaner shaft. In this deposit manganese minerals occur in nodules that are largely if not wholly confined to masses of manganiferous clay and wad formed by the replacement of residual clay in beds of shale. The masses of wad occur sporadically in a U-shaped zone roughly parallel to the limits of the partly decomposed underlying shale, which is relatively free from manganese. The composition of the clay is not known, but it is probably ferruginous kaolin formed in part by the decomposition of sericite. The deposit has been explored to a depth of 312 feet, but the deepest ore came from a depth of 260 feet, or 220 feet below the original water level.

2. Replacement masses in clay along a fault zone are well shown in the deposit near Dargan, Md., on the north side of Potomac River. In the narrow vertical zone of this deposit that was explored manganese oxides in the form of nodules and soft powder replace clay derived from the decomposition of shale breccia along an extensive thrust fault. The shale, which is composed of quartz, mica, and amorphous materials, is not so completely decomposed as the residual clay at Elkton, Va. Manganese ore has been mined at a depth of about 40 feet below water level. The Happy Creek deposit may belong to this type, but the clays resemble those at Elkton.

3. Replacement masses along pervious zones in schistose rocks are represented by the lenses of ore of the Piedmont mine, east of Lynchburg, Va., where relatively pure masses of manganese oxides replace quartz-mica schist along sharply defined nearly vertical zones. Some clay and wad are associated with the ore, but the mica of the replaced schist is fresh. The lens has been explored to a depth of 208 feet, or 170 feet below water level, and shows a maximum length of 125 feet and width of 30 feet. The adjacent wall rocks are undecomposed.

4. Replacement masses in channel sediment are illustrated by the deposit at Midvale, Va. This type of deposit, though noted by Penrose,¹ near Columbia, Tuolumne County, Cal., apparently has never been exploited commercially heretofore. At Midvale masses of manganese ore partly replace the clay which, with associated sand and gravel, fills a channel cut in limestone of Lower Cambrian age (Shady limestone). One border of the channel has been explored

¹ Penrose, R. A. F., op. cit., p. 494.

to a depth of 150 feet, but manganese ore appears to be confined to the higher levels. On the 50-foot level ore has been mined sporadically over an area about 100 feet square. As the original source of the clay is not known, the amount of alteration that has taken place can not be inferred. The sand and gravel have the properties of common river sediment.

RELATIONS OF THE DEPOSITS TO THE SURFACE.

All but one of the six deposits that are referred to in this paper are situated on the east side of the valley that lies west of the Blue Ridge and is commonly known as the Great Valley of Virginia. The other deposit lies well east of the Blue Ridge, in the Piedmont region. As most observers now agree that the manganese ores of the Great Valley and Piedmont regions have been deposited from solutions that derived their metal content from the weathering and erosion of the rocks in the neighborhood, the deposits may be examined in the light of their relation to the erosional history of the region.

The conditions that led to the development of the prominent surface features of Virginia and similar parts of the neighboring States have been the subject of considerable study. The most valuable contribution to the knowledge of these surface features is that of Hayes and Campbell,¹ who consider that those long stretches of the Blue Ridge in Virginia, which now rise to uniform elevations of about 2,300 feet, represent parts of an extensive erosion surface or peneplain which has been elevated and dissected. The few isolated peaks that rise considerably higher are regarded as having stood as mountains above this old erosion surface in consequence of their resistance to the processes of erosion. The peneplain is believed to have been established during late Jurassic and Cretaceous time and to have been elevated and warped during late Cretaceous time. It is known in northern Virginia and Pennsylvania as the Kittatinny peneplain. There appears to be no record of manganese deposits on the mountains that project above it.

In the west half of Virginia, especially east of the Blue Ridge, there are extensive areas of flat upland below which the larger streams have cut their valleys as much as 400 feet. Above this upland, which ranges in altitude from about 850 feet above sea level near Lynchburg to 1,400 feet near Staunton, project the long stretches of the Blue Ridge. This peneplain has been traced by residual areas over the region from central Alabama to eastern Pennsylvania. It is cut in the softer rocks, such as limestone and

¹ Hayes, C. W., and Campbell, M. R., *Geomorphology of the southern Appalachians*: Nat. Geog. Mag., vol. 6, pp. 63-126, 1894.

shale, and the ridges that project above it are composed of more resistant rocks, such as quartzite and siliceous metamorphic rocks. As the altitudes of the residual areas vary from place to place, it is concluded that this upland, like the higher peneplain, has been elevated and broadly warped in a somewhat similar manner. This upland, known as the Harrisburg peneplain, was formed during early Tertiary time and uplifted by several successive movements during late Tertiary time. After the first of these movements a third and still lower plain, known in Pennsylvania and New Jersey as the Somerville peneplain, was locally developed. This plain has been recognized in the Shenandoah Valley at Harpers Ferry, at about 530 feet above sea level, or 120 feet below the Harrisburg plain, but it is not easily distinguished from the Harrisburg plain at the south end of the Shenandoah Valley.

The relation of the outcropping part of each of the deposits described in this report to these erosion surfaces is quite clear. The highest point of the explorations of the Dargen deposit, near Potomac River, is about 350 feet below the early Tertiary peneplain, but a tunnel in the same fault zone 4,000 feet farther north, at the elevation of the Somerville peneplain, encountered a small quantity of manganese ore. In comparison with the relations of the other deposits, the fault along which this deposit lies should offer an exceptional opportunity for the circulation of underground water. The explorations of the Lyndhurst and Piedmont mines start about 50 feet below the average elevation of the early Tertiary peneplain, but the Midvale, Happy Creek, and lower Kendall & Flick deposits crop out approximately at the elevation of this peneplain. The higher Kendall & Flick deposit crops out nearly 150 feet higher than the peneplain, and the deposit worked in the Crimora mine, which was visited but not examined in detail, crops out where the peneplain merges with adjacent ridges east of Shenandoah Valley.

With regard to the relation of the outcrops to the local surface features, the Piedmont, Midvale, Happy Creek, and Dargen deposits are situated near the top or along the slopes of isolated hills or spurs, so that since dissection of the peneplain began they have received very little of the surface drainage or ground water that might contain manganese in solution. The Lyndhurst and Crimora deposits lie along stream channels sunk below the surrounding plain and therefore may have received accessions of manganese in solution. The fact that the deep levels of the Piedmont and Midvale deposits yield only a little water tends to show that the water they contain is now relatively stagnant. If, as there is good reason to believe, the manganese that now forms the masses of ore was brought to its present position in solution in ground water of local origin, the four deposits first named must have been formed during some

stage of early Tertiary erosion, when the surface features permitted the local drainage to reach the areas in which they lie.

It is possible that manganese deposits like those here described, as well as similar masses representing concentrations of other substances, such as iron oxide, might be formed either by regular but small accessions of material over a long period, such as that extending from early Tertiary time to the present, or by relatively rapid accumulation over a shorter period, or by both processes. It is thought that the relations of four of the deposits to the surface features preclude the first possibility, although, of course, manganese oxide may have been dissolved and reprecipitated to a slight extent within each deposit up to the present time. It is concluded, therefore, that the masses of the manganese oxide that now make up the deposits represent the rapid accumulation during a period geologically brief.

In determining more accurately the period during which accumulation of manganese oxide took place, the probable nature of erosion as shown by the relation of rock decay and solution to rock disintegration and removal in the region since the Cretaceous or Kittatinny peneplain was established must be considered.

The most favorable conditions for the formation of a manganese deposit probably exist when, through rock decay, large quantities of manganese oxide in solution are permitted to migrate along a zone that offers favorable conditions for deposition. With the uplift of the Kittatinny peneplain the gradients of streams and consequently their capacity for carrying sediment increased, and rock waste was removed as rapidly as it was formed. It seems probable that until the streams had cut their channels nearly to base-level, or the level represented by the early Tertiary peneplain, rock decay and solution were slight compared with rock disintegration and removal, although on account of the greater relief of the surface then than at any subsequent time oxygen-bearing waters were permitted to penetrate most deeply. It is also probable that during the period when the valleys were being broadened disintegration and removal were more effective than decay and solution, although not so much more as previously. The depth to which surface waters were permitted to circulate was probably as great during this period as before. From this period to that in which the peneplain was established over extensive areas of soft and soluble rock, rock decay and solution became more active than rock disintegration and removal, but on account of the low relief of the surface the zone accessible to surface waters was not so deep as previously, though it extended below the level of the streams.

During the period when peneplanation was being perfected locally there was probably little rock disintegration and removal, but solution and decay were going on in the zone accessible to migrating

waters that contained oxygen. At this time the best conditions for the solution of large amounts of manganese probably existed, but as the relief of the surface was low the opportunity for circulation in localized channels was poor. During the next stage in the erosional history of the region, that represented by the uplift of the early Tertiary peneplain, the gradients of the streams and consequently their capacity for transporting sediment were again augmented, but also with the increase in surface relief the opportunity was afforded for more active circulation of water to deeper levels.

In considering the effectiveness of the processes that went on during the last two periods in aiding the accumulation of manganese oxide it is necessary to balance the duration of the first period against the better facility for circulation during the second period. There is no doubt that the depth below the peneplain to which the ores are known to occur is a good reason for placing a considerable part of the accumulation in the last period, but it is also known that surface water may descend much deeper below the surface than the difference in elevation between the points of entrance and outlet,¹ a difference which on the early Tertiary peneplain was probably in some places as much as 100 feet. The data are not available at present to evaluate properly the relative importance of these two periods in the formation of the masses of manganese ore.

It may be noted that in examining that part of the Piedmont region in North and South Carolina in which gold deposits occur Graton² concluded that the thick cover of residual soil was formed during the later stages of peneplanation, before uplift had taken place.

There is good reason for regarding the sediments that contain the Midvale deposit as a remnant of an early Tertiary river-channel deposit. The similar material overlying the Happy Creek deposit and near the Elkton deposits may be either terrace or channel gravels.

It would be unwise without further study to assert that all the manganese deposits of Virginia or the region from Alabama to eastern Pennsylvania were formed during the early Tertiary period of erosion, but it is interesting to note that this suggestion was once made for the Appalachian deposits of iron ore, which have a similar areal distribution, as a result of the discovery of small basins of lignite of Tertiary age near Brandon, Vt.,³ and Pond Bank, Pa.,⁴

¹ Van Hise, C. R., Some principles concerning the deposition of ores: *Am. Inst. Min. Eng. Trans.*, vol. 30, pp. 55-58, 1900.

² Graton, L. C., Gold and tin deposits of the southern Appalachians: *U. S. Geol. Survey Bull.* 293, p. 13, 1906.

³ Hitchcock, Edward, Description of a brown coal deposit at Brandon, Vt., with an attempt to determine the geological age of the principal ore beds of the United States: *Am. Jour. Sci.*, ser. 2, vol. 15, p. 95, 1861.

⁴ Lesley, J. P., Lignite in iron ore at Pond Bank, Franklin County, Pa.: *Am. Philos. Soc. Proc.*, vol. 9, pp. 463-482, 1864.

near deposits of iron ore. It was then thought, however, that the residual iron ores within this entire region were the weathered residue of an essentially continuous horizontal iron-bearing bed. This assumption is not necessary, but it is reasonable to suppose that conditions during early Tertiary time may have favored, more than those of later periods, the solution and transportation of iron and manganese salts to favorable sites for deposition. The existence of many extensive deposits of residual iron ore and related laterite in regions having warm and moist if not tropical climates has long been recognized. In this connection it may be noted that Berry,¹ as a result of the study of the floras of the Upper Cretaceous and Eocene formations of the Coastal Plain of South Carolina and Georgia, concludes that the prevailing climate of that region at the time these beds were laid down was mild and humid, with possibly a brief period during Eocene time that was less mild.

Spencer² has noted that the large deposits of brown hematite of Mayari, in the Province of Oriente, Cuba, underlie an extensive rolling plain that is regarded as a remnant of a peneplain, possibly of late Tertiary age. Eckel³ states that most of the brown hematite ores of the Birmingham district were formed during Tertiary time.

PERSISTENCE OF THE ORES.

As they have considerable bearing on the successful exploitation of other deposits of manganese ores in Virginia, the data that have been gathered in the examination of these mines may be summarized. In the Niesswaner shaft, at Elkton, sporadic masses of ore were found 260 feet below the surface, although the richest zone was 50 feet or more higher. The deposit clearly replaces residual clay forming a pocket in shale. It is reported that ore was mined at a depth of 256 feet in the old Kendall & Flick shaft, but the nature of this deposit is not known. The lens of ore of the Piedmont mine was not appreciably smaller at the lowest level, 208 feet deep, than on the higher levels. According to Watson⁴ the greatest depth at which ore was found at Crimora is 198 feet, or 14 feet above the quartzite which underlies the deposit.

In some respects the origin of these manganese deposits resembles that of the iron ores of the Mesabi Range, Minn.,⁵ where extensive

¹ Berry, E. W., *The Upper Cretaceous and Eocene floras of South Carolina and Georgia*: U. S. Geol. Survey Prof. Paper 84, pp. 122, 158, 1914.

² Spencer, A. C., *Three deposits of iron ore in Cuba*: U. S. Geol. Survey Bull. 340, p. 318, 1908.

³ Eckel, E. C., *Iron ores, fuels, and fluxes of the Birmingham district, Ala.*: U. S. Geol. Survey Bull. 400, p. 149, 1910.

⁴ Watson, T. L., *Mineral resources of Virginia*, p. 249: *Jamestown Exposition Commission*, 1907.

⁵ Leith, C. K., *The Mesabi iron-bearing district of Minnesota*: U. S. Geol. Survey Mon. 43, 1903. Van Hise, C. R., and Leith, C. K., *The geology of the Lake Superior region*: U. S. Geol. Survey Mon. 52, 1911.

masses of soft hematite have been formed by the oxidation of the iron and solution of the silica contained in beds of "greenalite," a mineral composed essentially of ferrous oxide, silica, and water.¹ In the Mesabi district the ground-water level is about 75 feet below the surface,² and, although ores are locally found at a depth of 500 feet, most of the deposits lie within 300 feet of the surface.³

The conclusion may be tentatively drawn that in the Virginia-Maryland region aluminous minerals can be decomposed to amorphous clays to a depth of nearly 300 feet from the surface and 250 feet below water level, and that manganese ores may be formed in such clays from 250 to 300 feet below the surface. From analogy with similar deposits it is very doubtful whether manganese ores in any of these deposits will persist 500 feet below the surface, and a more probable limit is 400 feet. If all the manganese deposits of this region were largely formed during the early Tertiary erosion cycle, the lowest levels of the Dargan mine, 410 feet, represent the deepest explorations below the plain. The fault along which this deposit lies has probably offered exceptional opportunity for the deep circulation of underground water.

The different structural relations of the ores shown to exist among the mines described and the range in persistence of the different types of deposits emphasize the necessity for exhaustive areal study of the region near the deposits of such ores, in addition to the mine examinations ordinarily made.

PREPARATION OF THE ORES.

The machinery and methods used in the preparation of manganese ores for the market closely follow those used for the brown or limonite iron ores that occur throughout the region in which the manganese ores are found. Modern practice includes three operations—first, the treatment of crude ore in a log washer to free the nodules of manganese ore from the plastic clay in which they are embedded; second, the sizing of the coarse ore in trommels, where the smallest particles, generally those less than one-eighth inch in diameter, are rejected; third, the jigging of the separate sizes in order to eliminate the siliceous minerals from manganese minerals. Recently, in order to obtain the higher prices brought by finely ground ore, some companies have equipped their mills with drying and pulverizing machinery.

The modern log washer differs little from its early predecessor, except that the use of a steel frame permits the use of longer machines. It consists essentially of a central shaft 20 to 30 feet long,

¹ Leith, C. K., op. cit., p. 245.

² Idem, p. 235.

³ Van Hise, C. R., and Leith, C. K., op. cit., p. 186.

made either of a wooden beam or of structural steel, around which a series of logs or paddles are bolted so as to form a spiral. This shaft rotates with its axis inclined slightly from the horizontal and is suspended in a trough, so that when ore is added near the lower end it is slowly pushed up the trough and out of the higher end. A stream of water enters the higher end and carries away in suspension from the lower end the clay and fine particles mixed with the ore. Double washers contain two parallel shafts that rotate in opposite directions and give a greater output and a cleaner product.

Many mills are equipped simply with washers and attempt to recover only the coarse lumps of ore. Lumps that contain more silica than the limit permitted by makers of alloys must be crushed and further cleaned in jigs. For this purpose a jig of the common Harz type is used, but recently this has been superseded by jigs permitting closer control of the plunger action. Several mills have attempted to treat the sizes smaller than one-eighth inch on tables, but none appear to have made a marketable product successfully.

THE MINES.

PIEDMONT MINE.¹

LOCATION AND HISTORY.

The Piedmont mine, also known as the Lerner or Myers mine, is situated on a low knob adjacent to Beaver Creek, 2 miles south of James, Campbell County, Va., on the Norfolk & Western and Chesapeake & Ohio railways. James is 6 miles east of Lynchburg. (See fig. 4, p. 38.) It is reported that many years ago iron ore was drawn from pits in the neighborhood, several of which are situated between the two shafts marked 1 and 2 on figure 5, and the walls of an old stone furnace with piles of slag may be seen 3,000 feet north of the mine. Manganese ore was first mined here in the early nineties by the Lerner Mining Co. from pits near the Josephine shaft. From 1902 to 1912, under the ownership of the Piedmont Manganese Co., ore was drawn from the Josephine shaft to a depth of 105 feet, but the most vigorous development took place from 1912 to 1914. During this period the lessee, the Piedmont Manganese Corporation of New York, built a narrow-gage tramway from the mill to the Chesapeake & Ohio Railway, extracted ore to a depth of 150 feet from the Josephine shaft, and sank the new Oxford shaft 190 feet deep. The Oxford Mining & Manganese Co. sank the Oxford shaft to 208 feet in 1915 and mined ore to that level. The present owner is sinking the same shaft with the intention of mining the deeper ores. It is reported that the total yield

¹ Harder, E. C., op. cit., pp. 38-40. This mine should not be confused with the Piedmont mine in Nelson County.

from the Josephine shaft between the 105 and 190 foot levels was 5,052 tons, and the total production from all workings on the hill about 30,000 tons of washed ore.

SURFACE FEATURES AND GEOLOGY.

The Piedmont region in this part of Virginia is a relatively flat upland having an altitude of 750 to 850 feet above sea level, but a

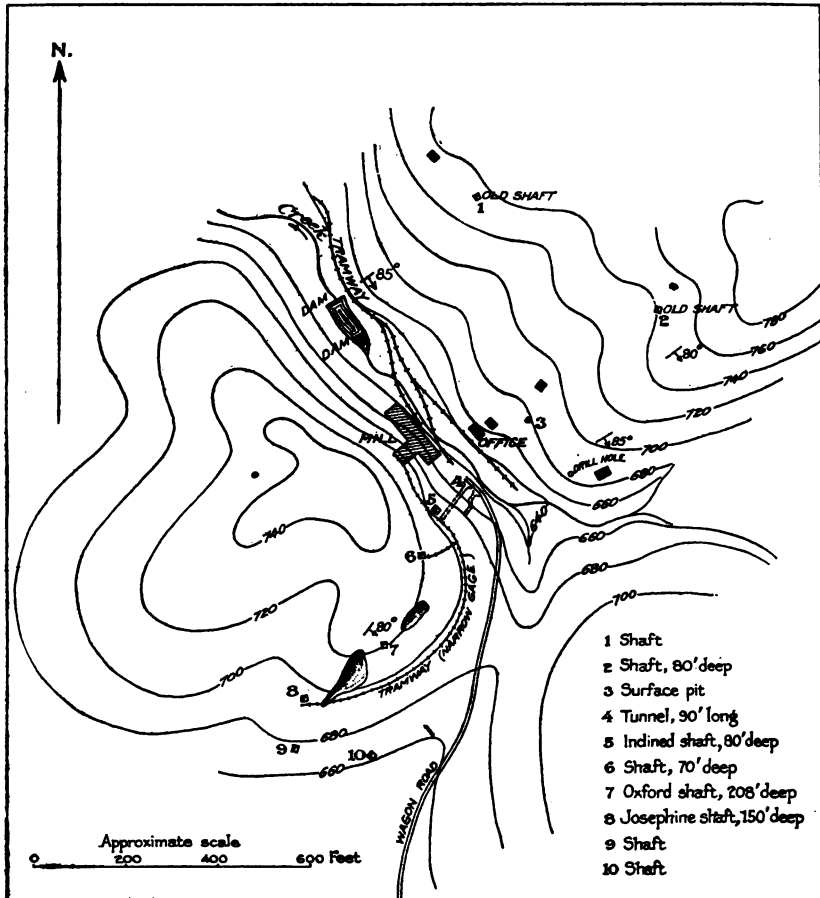


FIGURE 5.—Sketch map showing location of the workings of the Piedmont mine, Campbell County, Va.

few isolated hills and ridges rise to altitudes ranging from 1,100 to 1,400 feet. The principal stream, James River, flows in a narrow valley cut nearly 300 feet below the level of this upland, the normal stage of the river at James being 480 feet above sea level. The minor streams, such as Beaver Creek, also flow in narrow valleys cut 100 to 150 feet below the level of the upland. Where Beaver Creek meets James River there are small remnants of a terrace on

both sides of the river at an altitude of about 625 feet. As the upland probably represents the early Tertiary peneplain, these remnants may indicate a minor late Tertiary cessation in the downcutting of the valley, and are possibly equivalent to the Somerville peneplain of Pennsylvania and New Jersey.

The manganese deposits that have been most thoroughly explored lie on the south slope of a low knob that rises to an altitude of 750 feet, or about 100 feet above Beaver Creek, which almost encircles the knob. Ore has been mined from the 208-foot level of the Oxford shaft, 130 feet below the level of Beaver Creek and 170 feet below the original water level.

The rocks in the vicinity of the mine embrace a wide range of schistose types in which the planes of bedding and schistosity appear to coincide. Observations of strike range from N. 35° E. to N. 60° E. and of dip from 75° SE. to 80° NW. Beginning on the southeast, there are successive belts of gray to light-green muscovite schist with here and there clusters of magnetite grains and crystals of almandite garnet; a reef 50 to 75 feet wide of gray quartz-muscovite schist with numerous quartz lenses; and finally white crystalline limestone, locally with considerable dark-green chlorite mica, which forms the southeast wall of the manganese deposit. Northwest of the deposit greenish muscovite schist predominates, but there are also bands for fine-grained quartzite. Both pyrite and pyrrhotite are common in the schists and limestone. Between the mill and James River outcrops commonly show thin veins of pegmatite and quartz that lie parallel to the schistosity.

According to Watson¹ these rocks form part of a belt which extends the entire length of the Piedmont region in Virginia and which has been shown to contain sediments of Cambrian age.²

OCCURRENCE OF THE ORE.

Manganese minerals occur in many pits and trenches in the neighborhood of the Piedmont mine, but the larger masses appear to be confined to two belts that follow the schistosity of the rocks. The northern belt, which lies beyond the limits of the area shown in figure 5, has been prospected at three points over a distance of about 2,500 feet, but hard nodules of manganese ore have been found only at the northeasternmost point, where a 40-foot shaft was sunk some years ago. In this belt thin lenses of soft black manganese oxide alternate with bands of quartz-mica schist, forming zones that are locally as much as 10 feet wide but of unknown linear extent. In such zones manganese oxide appears to replace an unknown ingredi-

¹ Watson, T. L., Geological map of Virginia, Charlottesville, 1910.

² Watson, T. L., and Powell, S. L., Fossil evidence of the age of Virginia piedmont slates: *Am. Jour. Sci.*, 4th ser., vol. 31, p. 36, 1911.

ent in the schist, leaving the mica and much of the quartz unattacked. In one tunnel bands of soft manganese oxide contain coarse angular fragments of quartz, with relations which suggest that manganese oxide replaces the clay of a fault breccia, but this type of occurrence is unusual. The presence in this belt of hard nodules of manganese minerals in quantities that will be profitable to work has not yet been demonstrated.

In addition to sporadic pockets northeast of the mill, the southern belt contains two considerable masses of ore. The more southwestern and larger has been mined through the Josephine and Oxford shafts, and the other through shafts marked 5 and 6 on figure 5. These two masses are separated by an area of unaltered barren mica schist. Masses of soft manganese-bearing clay and wad were found in the tunnels at the point marked 4, but these tunnels have not yet disclosed much hard ore. The writer's observations of the larger deposit were confined to a part of the 208-foot level of the Oxford shaft, the Josephine shaft having been abandoned in 1913. The map showing the extent of the workings from these two shafts (fig. 6) is based on surveys by the company. The explorations from these shafts to a depth of 208 feet and for a horizontal distance of 175 feet show that manganese ore and clay formed a well-defined lens that pitched steeply to the southwest along the planes of schistosity. The maximum width on successively lower levels has ranged from 22 to 30 feet, and according to the maps of the several levels ore has been mined for a distance of 125 feet and explored a short distance farther. All the material from the lens was mined, and the yield of washed ore ranged from one-third to two-thirds of the weight of mine dirt. The average yield is considerably higher than any other on record from mines west of the Blue Ridge.

Harder,¹ who saw the mine in operation at the 80-foot level in 1909, gives the following description of the occurrence of the ore:

The ore occurs in kidneys or large masses and is mainly in the form of granular pyrolusite, either massive or with concentric structure. Crystalline pyrolusite and amorphous steel-blue psilomelane are associated with it but are much less abundant. Lenses of quartz, fragments of unaltered rock, and cavities lined with botryoidal surfaces likewise occur in the ore masses. The ore locally may compose 85 or 90 per cent of the ore-bearing layer, forming a nearly solid body with interstices filled with clay, while elsewhere more than half the layer may be clay in which the ore is embedded in lumps. The micaceous clay footwall is light brown, dark brown, or gray, by layers, and is residual from mica schist. The layers and schistosity have the same strike and dip as the ore-bearing layer. The footwall clay is similar to the clay associated with the ore and grades imperceptibly into it.

¹ Harder, E. C., op. cit., p. 39.

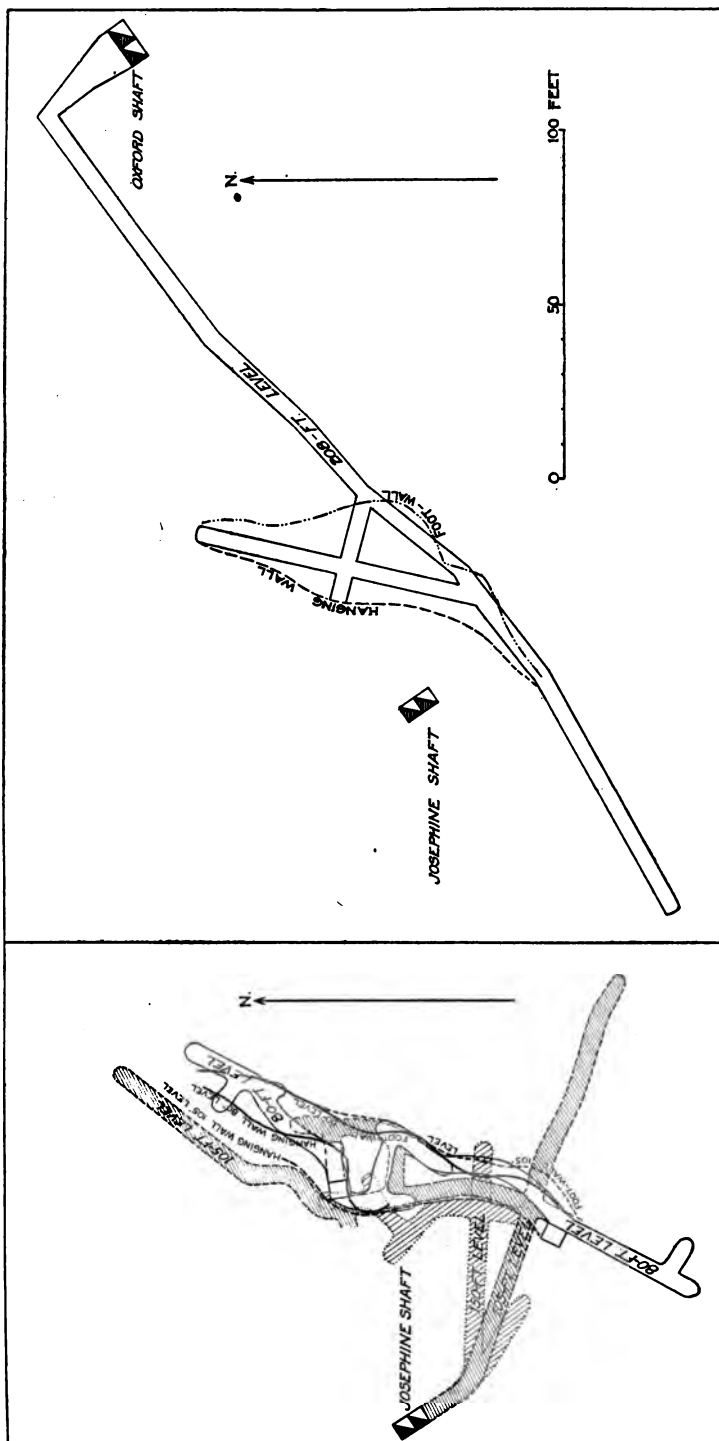


FIGURE 6.—Map showing principal underground workings of the Piedmont mine, Campbell County, Va.

Further exploration has thrown some doubt on the determination by Harder that the hanging-wall rock is altered granite, for it merges with normal quartzite and quartz-mica schist. The footwall mica schist has been found to be only a few feet thick and separated from the thick lens of limestone by a thin layer of wad. An interesting and unusual feature of the hard ore is the presence in all specimens of plates of mica, which here and there give the ore a laminated appearance, but elsewhere are distorted and sporadic. By the examination of several thin sections cut at right angles to the lamination it has been observed that layers of perfectly preserved chlorite and muscovite pass from residual masses of quartz into the adjacent manganese minerals, which have clearly replaced quartz in part. The extent to which manganese minerals have formed in manganiferous clay resulting from the decomposition of silicate minerals is not clear, but it is certain that a considerable part of the ore has been formed by the direct replacement of the quartz of quartz-mica schist.

ORIGIN OF THE ORE.

The largest lens of manganese ore has clearly been formed by the replacement of quartz-mica schist, possibly locally calcareous, by manganese minerals. The manganese has probably not been derived from the adjacent wall rocks, for they are fresh, and qualitative tests on the micas fail to show the presence of appreciable manganese. As the deposit crops out near the crest of a knob that has been isolated since the beginning of the dissection of the early Tertiary peneplain, it has probably received very little manganese since the peneplain was dissected. The deposit presents the interesting feature of a narrow lens of highly oxidized minerals of superficial origin persisting to a depth of more than 170 feet below water level and 130 feet below the nearest large stream.

MILLING.

The crude ore is delivered from bins to a jaw crusher and then to a 22-foot double log washer. The coarser material is sized in a trommel to three sizes, two of which are treated in four 3-compartment jigs, the coarse product being reground between rolls and added to the jig feed. In order to ship finely ground ore a 30-foot dryer, a Hardinge mill, revolving screens, and a Huntington mill were recently added to the plant.

MIDVALE MINE.¹

LOCATION AND HISTORY.

The Midvale mine is about 4,000 feet due east of Midvale, Rockbridge County, Va., on the Norfolk & Western Railway. (See

¹ Harder, E. C., op. cit., p. 65.

fig. 7.) The old mine workings are on the top of a broad spur that extends northwestward from South Mountain, a part of the Blue Ridge, at an altitude of 1,700 feet. A new tunnel extends northwestward under the old workings from a ravine 140 feet lower, and from the tunnel an aerial tramway extends to the mill near the railway, at an altitude of 1,120 feet. The mill contains a single log washer.

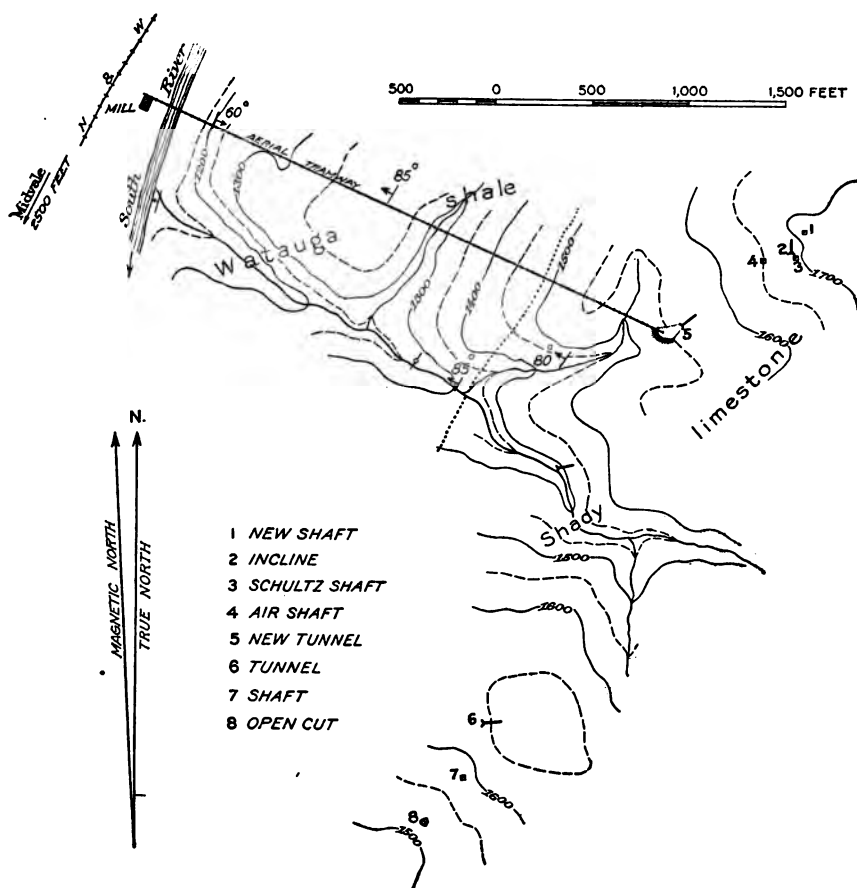


FIGURE 7.—Sketch map showing location of the workings of the Midvale mine, Rockbridge County, Va.

The property was opened in the early eighties and was subsequently worked by Cohalan, Irwin & Co., the Midvale Manganese Co., and Frank Schultz. The present lessee and operator is the Rockbridge Manganese & Iron Co. The production from 1909 to 1914, inclusive, was 914 tons, but there is no record of the earlier shipments other than 250 tons produced in 1887.

SURFACE FEATURES AND GEOLOGY.

In the vicinity of Midvale, South River flows in a narrow, flat valley at an altitude of 1,100 feet. The ridges that abut against the valley on the southeast are spurs from the long, high ridge known as South Mountain and are characteristically flat-topped, attaining altitudes that range from 1,600 to 1,700 feet. Numerous remnants of a flat upland are also to be seen northwest of South River at similar altitudes. There is warrant for believing that these flat areas, which are cut in highly inclined rocks of diverse character, represent portions of the early Tertiary erosion surface.

The rocks that underlie the area near the mines are exposed along the ravine southwest of the mine and the clearing adjacent to the tramway. The following section was measured:

Section near Midvale mine.

	Feet.
Red shales-----	100+
Gray and olive-colored shales, weathering brown. A few thin beds of dense gray limestone near the base-----	1,720
Dense gray and cream dolomite in beds 1 to 3 feet thick--	500+
	2,320

According to G. W. Stose¹ and Arthur Keith,¹ who have made reconnaissance examinations of this part of the Blue Ridge, the lowest unit is undoubtedly a part of the Shady or "Sherwood"² limestone (substantially the same as the Tomstown limestone of Maryland and Pennsylvania), and the upper units are a part of the Watauga ("Buena Vista"²) shale (probably the same as the Waynesboro formation of Maryland and southern Pennsylvania), all of Cambrian age. Farther east, beyond the limits of the area shown in figure 7, the main ridge of South Mountain is composed of nearly vertical beds of Cambrian quartzite, but no rock outcrops were found between the mine and the ridge. The mine workings appear to be above the dolomite beds that are well exposed in the ravine 500 feet to the southeast, and there are dolomite outcrops northwest and above the mouth of the new tunnel. With the exception of the uppermost shale beds near South River, which are inclined southeast, all the outcropping lower beds dip from 80° to 85° NW. There is little doubt, therefore, that the normal succession of rocks is present in this belt and that there are no faults of great magnitude in the vicinity of the mine.

¹ Personal communication.

² Campbell, H. D., The Cambro-Ordovician limestones of the middle portion of the Valley of Virginia: Am. Jour. Sci., 4th ser., vol. 20, p. 445, 1905.

OCCURRENCE OF THE ORE.

None of the explorations made prior to 1912, except the incline, are now accessible. The following explorations are reported: The Schultz shaft (3, fig. 7) with drifts at several levels; the incline with connected drifts (2); and the new shaft (1) with levels at 50, 70, and 105 feet, of which the 50-foot level was in 1914 extended through a connection with the incline, as shown in figure 8. The accessible explorations include the new tunnel (5) with connected drifts and the

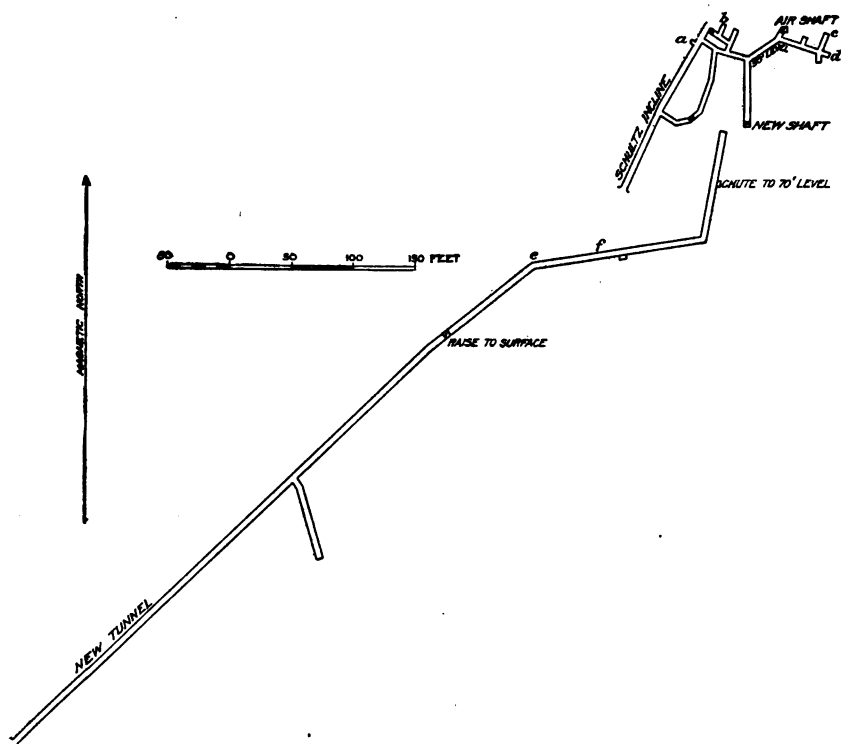


FIGURE 8.—Plan of the principal underground workings of the Midvale mine, Rockbridge County, Va.

50-foot level. The production since 1909 has come from the Schultz shaft, incline, and new shaft.

The drifts on the 50-foot level have struck manganese ore at a number of places, and most of the material mined during exploration has been washed. Although films of manganese oxide occur here and there on the tunnel level, no nodules of ore have yet been found. Typical modes of occurrences of ore are shown at *b* and *c*, figure 8. As in residual deposits of manganese ore, the manganese minerals are embedded in clay, but the properties of the clay in this deposit are such as to warrant a different explanation of its origin.

As seen in exposures on the 50-foot level the clay is generally sandy and contains here and there rounded pebbles of quartzite and quartz schist as large as 4 inches in diameter, as well as lenses of relatively clean reddish sand. Ordinarily the sand merges with the clay, but in a few places there is a sharp line of separation. Well-defined stratification is lacking. The clay is commonly mottled brown, but there are also patches of pure white, dark reddish brown, and pale rose-pink, the last a variety that resembles montmorillonite. The masses that are homogeneous in color are small. Pisolitic structure such as bauxitic clays commonly show is lacking, and although some varieties appear to contain considerable limonite, none harden on exposure, as most lateritic clays do.

In order to examine the properties of the coarse grains, several samples of sand and clay have been washed and screened with the results shown in the following table:

Screening tests of sand and clay from Midvale mine.

[Per cent.]

Sample.	On 20-mesh.	On 40-mesh.	On 60-mesh.	On 80-mesh.	On 100-mesh.	Through 100-mesh.	Clay in suspension.
1.....	0	0.6	1.8	0.6	0.6	2.8	93.0
2.....	1.2	8.1	17.0	6.2	4.8	18.7	44.0
3.....	3.0	7.3	9.4	4.2	3.3	17.0	55.8
4.....	15.7	4.7	3.4	1.3	1.4	4.5	69.0

1. Lens of mottled brown and red sandy clay from point marked *a*, figure 8. The sands are largely flat angular grains of fine-grained quartz, with a few of psilomelane. Rounded grains are lacking.

2. Red sand from point marked *c*, figure 8. Most of the grains above 60-mesh are well-rounded quartz. There are a few coarse grains of quartzite. Relation of sizes is that of normal stream sand.

3. Light reddish-brown sandy clay from point marked *d*, figure 8. Very similar to No. 2 except that there are more coarse quartzite grains.

4. Dark-brown to black wad, with manganese nodules, adjacent to No. 3 at point marked *d*, figure 8. There are only a few rounded quartz grains. Sand is largely psilomelane grains, one of which was 10.6 per cent of sample.

There can be little doubt that the sands from Nos. 2 and 3 are stream worn and not formed by residual decay or brecciation. Although most of the grains are single grains of quartz, many are, like the larger pebbles found in the clay, quartzite and quartz schist, closely resembling the Cambrian quartzite that underlies the Shady limestone. The grains of No. 1 are angular and the faces of some present a mammillary appearance. They are composed of microgranular quartz and appear to be fragments of minute veinlets of secondary origin.

The pebbles found on the 50-foot level range in size from coarse sand to pebbles 4 inches in diameter and in shape range from sub-angular to well rounded. They do not occur in defined lenses but are scattered here and there in both the sand and the sandy clay. In many of them the cementing material is decomposed and the pebbles crumble under slight pressure. On the new tunnel level sand

predominates over clay and there are more pebbles that tend to occur in lenses. Near the point marked *f*, figure 8, on the level a rounded boulder of quartzite 36 inches long was embedded in sandy clay and a few feet farther north decomposed siliceous dolomite was struck on the floor of the drift. A raise near the face of the tunnel has cut a zone of gravel-bearing sand. The relations of the materials on this level strongly suggest that the tunnel has been run close to the bottom and near the west edge of a filled river channel. Although the channel appears to trend northeast, the east limit and shape have not been determined.

The entire mass of clay and sand is wet, but there are few water-courses and little water flows from the mine workings. The clay is sufficiently plastic in places to flow slowly through small open spaces between the lagging in the drifts.

The hard manganese ore appears to be confined to highly irregular masses of dark-brown wad and manganiferous clay embedded in the variegated clay. No ore or wad has been found in the zones of sand. The masses of wad have a great range in size and shape and the limits of the larger bodies have not been determined. Some are rudely lenticular and are disposed in various positions. Locally the limits are sharply defined, but generally wad merges with reddish-brown clay. It is possible that certain horizontal zones contain more manganese than others, but this has not been determined.

Psilomelane is the commonest manganese mineral in the washed product. It forms both rounded or botryoidal nodules and slag-like stalactitic masses. Some nodules show considerable manganite, much of which forms terminated crystals lining cavities. One polished section shows nuclear masses of fine crystals of manganite enveloped by numerous alternating fine bands of psilomelane and manganite. These two minerals appear to have been deposited alternately, but at one place in the specimen manganite may have been formed by the hydration of psilomelane. Limonite nodules have been found sporadically on the 50-foot level.

The following analysis was furnished by Mr. H. L. Whitney, manager of the mine:

Analysis of washed ore from Midvale mine.

MnO ₂ -----	79.20	Co-----	0.79
MnO-----	2.79	Ni-----	.26
Fe ₂ O ₃ -----	3.07	SiO ₂ -----	2.11
Al ₂ O ₃ -----	3.56	P-----	.113
CaO-----	.33	S-----	.045
MgO-----	.34		
BaO-----	2.99		95.658
Cu-----	.06	Mn-----	52.23
Zn-----	Tr.		

The yield of washed ore has not been accurately determined, except on a small scale on material from the manganiferous clay. Samples run from 25 to 50 per cent concentrate of all sizes down to fine sand. The ordinary log washer does not, however, recover lumps smaller than half an inch, so that under milling conditions the yield would probably be lower than this figure.

In addition to the deposit that has been the scene of recent operation, old explorations indicate the existence of a similar deposit on another spur from South Mountain, 3,000 feet to the southwest. Well-rounded quartzite pebbles were noted both in the clay exposed in the tunnel walls (No. 6, fig. 7) as well as on the dump. Ore was taken from these workings and hauled to South River valley for washing. According to aneroid-barometer measurements the lowest explorations in gravel-bearing clay on this hill coincide closely in altitude with the new tunnel on the northern deposit. No rock outcrops were observed near the southern deposit.

ORIGIN OF THE ORE.

The coarse gravel and boulders, as well as the sand contained in the clay of the northern deposit, are such as are characteristic of river sediments rather than residual or fault-zone clays. The coarse sediments resemble the rock of which the high ridge 1,500 feet east of the deposit is composed but are entirely different from the rock that underlies it, as shown by exposures underground and in adjacent ravines. The angular grains of quartz washed from one specimen of clay are probably parts of veinlets deposited from the solutions with which the clay is saturated. It is suggested that these manganese deposits occur in remnants of channel sediments laid down by a river that flowed on the surface of the early Tertiary peneplain. As the manganese nodules show no evidence of rounding by attrition or crushing, it seems probable that they have been formed in the manganiferous clay where they are now found. Although the extent of the ore-bearing clay is not known, the amount of manganese in the channel filling is clearly greater than is present in ordinary sediment. Manganese has therefore probably been brought into the channel from outside sources by circulating solutions, but as both deposits occur on spurs which since the dissection of the Tertiary plain have received little surface drainage or underground water, it is clear that the deposition of the manganese must have taken place in early Tertiary time, before the plain was dissected.

If this explanation of the origin is correct, the manganese minerals will probably be found only in the river sediments. The underlying dolomite is much decomposed, but whether it originally contained sufficient manganese to yield workable deposits by weathering alone is doubtful.

LYNDHURST MINE.¹

The Lyndhurst mine lies west of Buck Creek, 2 miles southeast of Lyndhurst station, Augusta County, Va., on the Norfolk & Western Railway. According to Weeks² the first opening was made in 1859. In 1885-86 there was considerable development by the Virginia Manganese Mining Co., which obtained some ore from a shaft 65 feet deep. After another lapse the property was worked by Kendall & Flick for several years, until 1908, when it was finally abandoned. Although none of the underground workings were accessible in 1914, the deposit is mentioned here because the character of the material on the dump and the relation of the explored zone to the early Tertiary peneplain suggest a similarity to the conditions found in the Midvale deposits.

The collars of the old shafts are on a terrace 15 feet above the bed of Buck Creek and about 50 feet below the level of the early Tertiary peneplain, which in this vicinity has an altitude of 1,450 to 1,500 feet and is but slightly trenched by the present drainage. The material on the dump contains numerous well-rounded pebbles and boulders of quartzite and chert, and in many of the lumps of psilomelane there is considerable well-rounded as well as angular sand and gravel. Although some ore occurred near the surface, a 20-foot zone was encountered at a depth of 65 feet that was richer in ore than the higher ground.³

There are no rock outcrops in the vicinity.

KENDALL & FLICK MINE.⁴**LOCATION AND HISTORY.**

The Kendall & Flick mine, also known as the Mary Campbell, comprises two groups of workings on the north slope of an isolated hill a mile south of Elkton, Rockingham County, Va. (See fig. 9.) The older workings, consisting of several open cuts, shafts, and tunnels that lie along a deep ravine tributary to Shenandoah River, were operated intermittently between 1888 and 1909, and a considerable tonnage of iron and manganese ores was shipped. The newer workings, 2,000 feet to the north, consist of several pits and a shaft with extensive underground drifts, which were opened in 1910 and operated almost continuously until January, 1915.

The material taken from the old workings was hauled in wagons to a mill on the Norfolk & Western Railway, a mile to the north, to be washed. This mill burned in 1909, and in 1911 a modern mill was built on the same site.

¹ Harder, E. C., op. cit., p. 62. Fontaine, W. M., Notes on the mineral deposits at certain localities on the west part of the Blue Ridge: The Virginias, p. 55, 1883.

² Weeks, J. D., U. S. Geol. Survey Mineral Resources, 1885, p. 317, 1886.

³ Idem, p. 315.

⁴ Harder, E. C., op. cit., p. 57.

SURFACE FEATURES AND GEOLOGY.

In the vicinity of Elkton there are numerous flat spurs from the hills east and southeast of the town that attain an altitude of 1,000 feet, as well as extensive level areas farther west at the same altitude. These flat areas are considered to be remnants of the early Tertiary peneplain. Shenandoah River and its tributaries, such as Elk Run, flow in channels cut from 50 to 75 feet below this plain. The collar

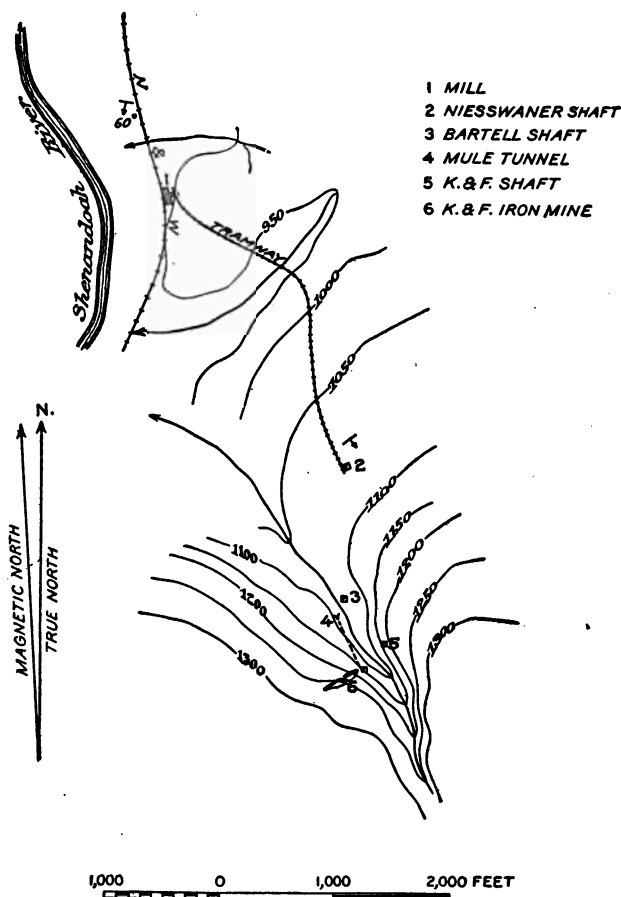


FIGURE 9.—Sketch map showing location of the workings of the Kendall & Flick mine, near Elkton, Rockingham County, Va.

of the Niesswaner shaft, at an altitude of 1,075 feet, or 153 feet above Shenandoah River, is on a gently sloping bench that merges with the plain to the north. The collar of the old Kendall & Flick shaft is about 140 feet higher. Another shaft about 1,200 feet northeast of this shaft and about 50 feet higher is reported to have struck, at a depth of 110 feet, or about 1,165 feet above sea level, a lens of coarse,

well-rounded quartzite boulders apparently lying on shale and sandstone bedrock. The material is clearly waterworn, but it is not certain whether the boulders lie on a terrace or in a channel.

No exposures of bedrock were noted in the area between the Kendall & Flick open cut and the mill, but time did not permit an exhaustive search. Gray shale and thin-bedded limestone are exposed in the railroad cut 600 feet north of the mill. These beds are locally crumpled, but the strike is east and the dominant dip 60° S. The Niesswaner shaft passed gradually from the clay in which manganese ore was found into soft, decomposed shale and finally, at a depth of 270 feet, into hard, mud-cracked red shale. The mud cracks show that the shale is not overturned. The face of the west drift on the 300-foot level also shows similar shale with a strike of N. 30° E. and dip of 10° SE. Decomposed buff shale having a strike of N. 30° E. and dip of 50° E. was also seen in the face of the west drift of the 206-foot level.

The shales of the Niesswaner shaft are tentatively regarded as belonging to the upper part of the Watauga shale, but the correlation of the beds in the railroad cut is uncertain. The local physiography indicates that the structure on the west flank of the Blue Ridge may be complex, and considerable areal work may be necessary to determine the correlation and broader structure of the beds in which the deposits are found. The manganese deposit appears to be inclosed in a pocket of clay, resulting from the decomposition of the red shale in place.

OCCURRENCE OF THE ORE.

With the exception of the open cut (No. 6, fig. 9), none of the openings made by Kendall & Flick were accessible in 1913. The main shaft (No. 5) is reported to have been 256 feet deep when work was abandoned in 1909, but there is no record of the occurrence of the ore. Iron ore only was taken from the open cuts, but it is reported that some manganiferous ore was obtained from the deep workings and removed through the mule tunnel (No. 4). The walls of the eastern open cut show decomposed sandy shale, here and there impregnated with limonite and containing thin films of manganese oxide. During 1915 a new shaft (No. 3) was sunk to a depth of 135 feet in the ravine, but encountered only valley wash containing subangular boulders of quartzite.

It is reported that the amount of ore mined above the 140-foot level of the Niesswaner shaft was not great, but the upper work was not accessible in 1913. This shaft reached a depth of 312 feet in May, 1914, but no ore was found below 260 feet, or 105 feet below the level of the Shenandoah River, 3,000 feet distant, and 220 feet below

the original water level. Most of the crude ore that yielded the output from 1912 to 1914 came from the ground between the 140-foot and 206-foot levels. As shown by the sections of figure 10, the zone which yielded the ore, and was therefore most thoroughly explored, was roughly U-shaped in cross section and about 30 feet in maximum thickness on the arms. The explorations do not appear to have determined the horizontal limits of the ore-bearing zone, except at the face of the southwest heading, where decomposed shale was found. Within this zone hard rounded and slaglike masses of manganese minerals were found, for the most part in dark-brown to black wad, which formed highly irregular bodies in soft variegated clay. Locally, however, the manganese minerals were embedded in pure ocher containing little manganese, but none were observed in white or pale-yellow clay. Although some bodies of wad were small and apparently isolated, many of the larger bodies were connected by irregular pipes and seams of wad, and by following these it was possible to locate new bodies in the zone. As the explorations and stoping tended to follow the ore, the result in places was a veritable maze of drifts and raises.

Although the round ore nodules are generally solid, many of the slaglike masses are cavernous and stalactites of psilomelane hang vertically from their walls. Psilomelane appears to be the commonest mineral, but many nodules show manganite and psilomelane in alternate bands, and in several places manganite crystals fill fractures in psilomelane. It is reported that in systematic sampling the crude ore yielded washed ore in the ratios of 3 to 2 and 3 to 1; but from the mill records it is doubtful whether a ratio of 3 of crude to 1 of washed ore was maintained over long periods. A few masses of ore weighing as much as 500 pounds have been found, but most of the nodules range from 1 inch to 4 inches in diameter. In addition to ore the washed product contains subangular fragments of microcrystalline quartz that resemble chert and range in size from fine sand to pieces 2 inches in diameter. Fragments of sedimentary rocks have never been found in the mass.

The clay adjacent to the ore bodies is commonly yellowish brown, but here and there variegated, white, gray, and dark brown. It merges both laterally and below into a zone of pale-brown decomposed shale, in which traces of bedding may be recognized. No hard nodules of manganese occur in this shale, although there are films of manganese oxide here and there along bedding planes. The thickness of this zone appears to range from a minimum of about 20 feet under the deposit in the shaft to more than 90 feet on the 206-foot level.

Although the important crystalline constituents of the clay have been recognized under the microscope, the exact nature of the changes

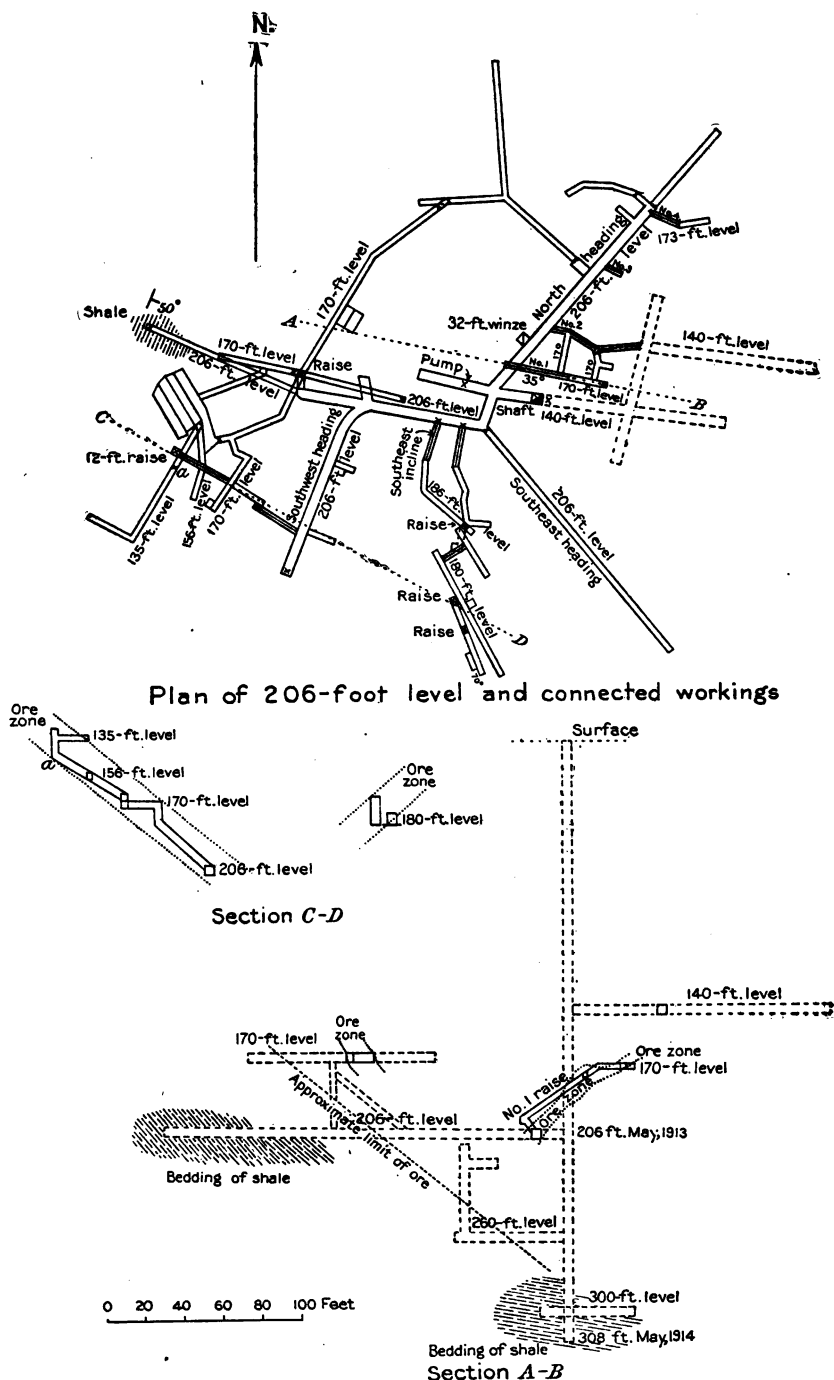


FIGURE 10.—Plan and cross sections of the Niesswaner shaft, Kendall & Flick mine, near Elkton, Rockingham County, Va. X, limit of accessibility in underground workings.

undergone by the shale in decomposing to clay can not be determined, because the colloidal materials that make up the bulk of the clay appear similar and may, nevertheless, show a wide range in composition. The unaltered coherent shale contains considerable sericite, ferric oxide, clay, quartz, and possibly minor accessory minerals. The soft shale at the face of the west drift on the 206-foot level also contains sericite, clay, and quartz, but, except for the change to a soft yielding mass, does not appear to differ greatly from the unaltered shale. Some of the clay near wad and nodules of manganese minerals is gray or white and contains considerable sericite and quartz, but most of it is yellowish-brown clay substance with very little sericite and quartz. Some specimens contain angular platy fragments of microgranular quartz and others, such as that collected at the point marked *a*, figure 10, contain numerous minute quartz crystals, with many calcite nuclei. Both these forms of quartz appear to be secondary in the clay and to be formed as a result of the decomposition of the shale.

The comparison of the partly altered shale and clay appears to indicate that much of the clay substance has been formed by the decomposition of sericite. If the clay approaches in composition that of kaolin, in which the ratio of silica to alumina is the same as in sericite, silica is not necessarily set free. It is possible, however, that the decomposition of sericite might yield potassium carbonate, which is capable of dissolving quartz at one place and depositing it at another. The alteration of sericite to kaolin may take place with little change in volume, and it is therefore possible that the clay in which the manganese occurs and is commonly called residual clay may represent essentially an equivalent volume of shale.

The purpose of the study set forth above was to ascertain whether it is more probable that the masses of manganese ore, which obviously represent more than that contained in a volume of fresh shale equal to that of the clay, represent an enrichment of manganese through loss of shale constituents by solution or whether the volume of the clay has remained essentially constant and manganese has been added. If the clay has approximately the composition of kaolin, the latter assumption appears more reasonable.

ORIGIN OF THE ORE.

The relations of the hard manganese minerals to wad and clay suggest the following mode of origin: The clay in which the manganese is found was in part a constituent of the original shale and in part has resulted from the decomposition of sericite. Hydrous oxide of manganese, partly an original constituent in the shale but largely brought into the clay mass in solution, first replaced the clay by forming segregated masses of soft wad. Locally masses of fairly pure

but incoherent hydrous manganese oxidé were formed. The nodules of ore have formed in wad, largely by the deposition of successive bands of psilomelane and manganite, but partly by the replacement of clay.

MILLING.

In the new mill erected in 1911-12 the mine dirt is elevated to bins, from which it is fed to a trommel with $1\frac{1}{2}$ -inch holes. The oversize, consisting of nodules of ore and masses of mud, is crushed in rolls and joins the screened product, and both pass through a double log washer. The washed ore is sized in a double trommel to three products, the coarsest of which, above $1\frac{1}{2}$ inches, is hand sorted, while the middling, ranging from $1\frac{1}{2}$ inches to one-fourth inch, is sized and jigged in a McLanahan jig. An attempt was made to treat the finest material on a Wilfley table, but it was abandoned, as a high-grade product could not be made.

HAPPY CREEK MINE.¹

LOCATION AND HISTORY.

The Happy Creek manganese mine, operated by the Seibel Iron Mines (Inc.), lies on the north end of a low knob 3 miles east of Front Royal, Warren County, Va. The iron mine that was operated for a number of years by the same owners is 1 mile farther south, at the south end of the knob. Although the occurrence of manganese here has been known for a number of years, most of the present workings, consisting of two open cuts and several shallow shafts and pits, have been made since 1907. During 1914 manganese ore was mined by a steam shovel from a 45-foot face of the northern open cut, and carried by narrow-gage tramway to the mill near Happy Creek, on the Southern Railway, 2,000 feet distant.

SURFACE FEATURES AND GEOLOGY.

Both mines are situated approximately at the line where the knob merges with the dissected upland, at an altitude of 800 feet. The channel of Shenandoah River, 2 miles to the north, is cut 350 feet below this upland, which is well developed along the valley both northeast and southwest of Front Royal. -

Rock outcrops are poor in the vicinity of both mines, except along the knob and in the face of the largest iron-ore quarry. Here flat-lying beds of quartzite containing interbedded lenses of quartz abut against a mass of angular quartzite débris and clay that appears

¹ Harder, E. C., op. cit., p. 55.

to be fault breccia. The sandstone is regarded as the Antietam sandstone of Lower Cambrian age, and probably makes up most of the knob. West of the manganese mine there are outcrops of dense gray limestone and reddish shales, with northeast strike and varying southeast dip, which undoubtedly correspond to higher formations than the Antietam sandstone. The relations of these beds indicate the presence of a thrust fault along the northwest edge of the knob, but its exact position has not been determined. This inference is strengthened by the geology of the west flank of the Blue Ridge in the Harpers Ferry quadrangle,¹ the southwest corner of which lies 8 miles northeast of Happy Creek. In this region there are two thrust faults, the western of which if projected would pass east of Happy Creek near the manganese mine.

OCCURRENCE OF THE ORE.

The best exposures of ore are shown in the face of the northeast open cut, which is about 300 feet long and covers slightly more than an acre. Little ore is exposed in the other open cut, which lies about 250 feet to the southwest and covers about a quarter of an acre. At the first location hard slaglike masses of manganese minerals are sporadically distributed in yellowish-brown clay in two nearly vertical lenticular zones which range from 5 to 8 feet in width and trend south. There is little difference between the color of the clay in which the manganese minerals occur and that of the clay immediately adjacent, although elsewhere the manganese-free clay is mottled reddish brown, light brown, and white.

The hard manganese minerals here do not appear to be confined to masses of wad and manganiferous clay, as they are in some other deposits on the west slope of the Blue Ridge. Small irregular patches of wad occur here and there in relations which show clearly that the wad replaces clay, but it forms a small part of the mass. The nodules range in size from very small grains to some 8 inches in diameter. Many show an inner zone of concentric bands of radiating crystals of manganite enveloped in botryoidal psilomelane. Limonite nodules are also present, and to get a good grade of manganese ore for shipping these must be eliminated by sorting. In mining only the richest zones are selected, and ordinarily two carloads or about 8 cubic yards of mine dirt yield 1 ton of ore. When the proportion of limonite becomes too great to be profitably eliminated by sorting, a mixed iron and manganese product is shipped. The ratio of washed to crude ore may then rise to 1 ton to 3 cubic yards.

Along a part of the west face of the large open cut a poorly defined bed of boulders, coarse gravel, sand, and clay about 15 feet

¹ Keith, Arthur, U. S. Geol. Survey Geol. Atlas, Harpers Ferry folio (No. 10), 1894.

thick is exposed, and although it contains some wad, it appears to overlie the mass of manganese-bearing clay. The gravel contains well-rounded pebbles of chert, quartzite, and sandstone, the largest 18 inches in diameter.

The underlying clay adjacent to the manganese zones yields, after the flocculent part is washed away, about 5 per cent of residue that is principally angular quartz sand, with a few grains of psilomelane and many minute quartz crystals containing nuclear grains of calcite and clay substance, such as occur in the clay near ore in the Niesswaner shaft, near Elkton. The surfaces of the quartz crystals are pitted, but there is no evidence of abrasion and they appear to have formed in the clay. The flocculent part contains traces of sericite. This clay is not so clearly stream-channel material, but resembles the residual clay of the Elkton deposit.

ORIGIN OF THE ORE.

Only a superficial zone of this deposit has been explored, and, as in many other places, this zone contains considerable limonite together with manganese oxides. Although a fault plane probably lies within a short distance of the deposit, it is not certain that the ore is confined to the fault. The clay with which it is associated may be derived in part from shale of one of the Cambrian formations. The presence of the ore under stream gravel lying on the early Tertiary peneplain appears to be significant.

MILLING.

At the mill crude ore is dumped into the lower end of a double log washer, from which the clean coarse material is delivered by a belt to a trommel. This delivers sizes of 1 and 2 inches and an oversize which is crushed in a jaw crusher, elevated, and separated into two sizes in a second trommel. All material between 1 and 2 inches is treated in a one-compartment coarse jig, which produces shipping ore and a product that is crushed in Cornish rolls and returned to the second trommel. A two-compartment jig treats the material between half an inch and 1 inch and yields shipping ore and tailing. A three-compartment jig treats the fine material and delivers shipping ore and tailing. This plant has produced 300 tons of washed ore a month.

DARGAN MINE.

LOCATION AND HISTORY.

The Dargan mine is on the north side of Potomac River about a mile southwest of Dargan, a settlement in Washington County, Md.

(See fig. 4, p. 38.) It is reported that it was opened by a shaft near the Chesapeake & Ohio Canal in the early seventies, but the most serious attempt to exploit the deposit extended over the period 1908 to 1910, when a new shaft was sunk in an open cut to a depth of 50 feet and drifts were run 190 feet to the north. As the result of sporadic explorations in a 50-foot vertical zone 60 tons of good-grade lump ore and 90 tons of low-grade washed ore were mined.

SURFACE FEATURES AND GEOLOGY.

Although this deposit has produced little ore, a description of it is warranted because the structural relations are so clearly shown in the natural exposures and mine workings, and because it appears to have unique physiographic relations. The mine workings lie at the south end of a narrow ridge that rises 720 feet above sea level, or about 70 feet above the level of the upland that represents the early Tertiary peneplain. The collar of the shaft is 290 feet above sea level, or 25 feet above the normal stage of the river, and at a point 100 feet north of the river manganese ore has been mined 25 feet below water level, or about 410 feet below the level of the early Tertiary plain.

There are numerous exposures of gray and brown micaceous sandstone along the crest of the ridge and of hard gray micaceous shale lower down, which are referred by Keith¹ to the Antietam sandstone and Harpers shale, respectively. Both are inclined steeply to the east. As shown by exposures west of the mine workings, the beds of shale abut against the beds of limestone that form the east limb of a low anticline. This limestone is referred by Matthews and Grasty² to the Tomstown limestone, which normally overlies the Antietam sandstone and Harpers shale. There is little doubt that the contact between the Harpers shale and the limestone, as shown by Keith, is a thrust fault of considerable magnitude. Explorations for manganese ore are confined to the zone of decomposed rock that lies along this fault.

OCCURRENCE OF THE ORE.

The shaft and connected drifts were not accessible at the time of examination (May, 1912), but several faces of drifts from the open cut showed manganese minerals. These form hard slaglike nodules of roughly spherical shape, with a maximum diameter of 20 inches. Most of these nodules are made up of alternating concentric layers of psilomelane and manganite, which separate when struck with a

¹ Keith, Arthur, U. S. Geol. Survey Geol. Atlas, Harpers Ferry folio (No. 10), 1894.

² Matthews, E. B., and Grasty, J. S., The limestones of Maryland: Maryland Geol. Survey, vol. 8, pt. 3, p. 401, 1909.

hammer. No brown manganiferous wad was found, but there are irregular patches of soft pyrolusite that replaces clay. The clay in which the nodules occur is variegated light yellowish brown to brown and contains numerous impressions of angular shale fragments which show that it is largely a decomposed fault breccia. Although the color of the clay is clearly due to hydrated iron oxide, no nodules of this mineral have been encountered.

According to the available data explorations were confined to a zone adjacent to the limestone on the west, not more than 50 feet wide, although in an incline from the south into the old workings the shale is decomposed over a greater width. It is reported that the fresh limestone presented a very irregular rounded surface toward the fault-breccia clay, a feature that suggests corrosion of the limestone by circulating solutions.

The fault zone has been explored by a tunnel on the west side of the ridge at a point 4,000 feet north of the old workings near the canal, and although only a few manganese nodules were found, the fault breccia has the same characteristics.

No record of the amount of washed ore yielded by a definite quantity of crude ore has been kept, but the proportion appears to have been rather low.

ORIGIN OF THE ORE.

If, as appears to be the case with the other deposits, the Dargan deposit was largely formed during the early Tertiary period of erosion, ore must have extended about 410 feet below the adjacent surface at that time, or 150 feet lower than the limit of ore at Elkton. The amount of ore mined in the deepest zone of the Dargan deposit is small compared to that taken from the other deposits, and it may be that the lower limit of ore was reached. The ease with which the fault zone permitted the circulation of ground water, however, may account for the greater depth to which ore was deposited.



DEPARTMENT OF THE INTERIOR

FRANKLIN K. LANE, Secretary

UNITED STATES GEOLOGICAL SURVEY

GEORGE OTIS SMITH, Director

Bulletin 640—D

**MOLYBDENITE AND NICKEL ORE IN
SAN DIEGO COUNTY
CALIFORNIA**

PAPERS BY

F. C. CALKINS

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II

MOLYBDENITE NEAR RAMONA, SAN DIEGO COUNTY, CALIFORNIA.

By F. C. CALKINS.

INTRODUCTION.

Molybdenite is said to have been discovered at several places in San Diego County, Cal. The occurrence that has received most notice was visited by the writer in December, 1915. It lies about 6

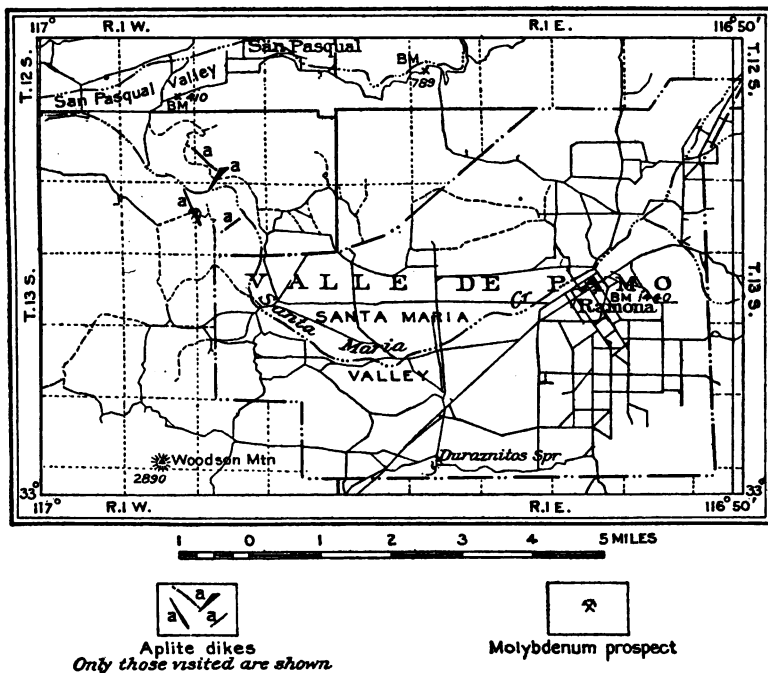


FIGURE 11.—Map showing location of aplite dikes and molybdenum prospect near Ramona, San Diego County, Cal.

miles west of Ramona, on property held by the Molybdenum Syndicate (Ltd.), of San Diego. (See fig. 11.) Ramona lies by road 37 miles northeast of San Diego, whence it may quickly be reached by any one of two or three automobile stage lines. A carriage or auto-

mobile may be taken within less than a mile of the prospect, the remainder of the distance being covered by an old road that was in disrepair at the time of visit.

Ramona lies in one of the many basin-like valleys which stand at various levels amid the mountains east of San Diego and whose origin and relations present an interesting physiographic problem that can not be discussed in the present paper. Santa Maria Creek passes from the Ramona basin to the much lower one of San Pasqual through a gorge of remarkably steep gradient. The molybdenum prospect is situated on undulating ground that overlooks this gorge from the south.

Natural vegetation is scanty about Ramona. No native trees except scrub oak grow nearer than some of the higher summits that form the sky line. Brush grows thickly on the shadiest slopes, but the surface is for the most part barren to a degree that favors easy prospecting.

GEOLOGIC CONDITIONS.

- The dominant rock about Ramona, as well as westward to the foot of the mountain range, is one that would commonly be called a biotite granite. Its color is gray with a tinge of olive-green; its texture is moderately coarse. Feldspar is its most abundant mineral, but quartz is also abundant, and small flakes of black mica occur in moderate quantity. Microscopic study shows that the rock is not a typical granite, inasmuch as the alkali feldspar is very subordinate to the soda-lime feldspar.

This granitic country rock is cut by many dikes of aplite. The aplite is made up of the same constituents as the granite, but as it contains less biotite, it is light in color, being pale gray to nearly white when fresh; in places, however, it is stained with red oxide of iron. The microscope shows that it contains a large proportion of microcline. Aplite is harder and less readily weathered than granite and therefore commonly stands forth in relief on the surface. This is strikingly true of the aplite in the hills about Ramona, where many dikes, especially one on the crest north of the Santa Maria Creek gorge, appear at a distance like walls built by human hands.

MOLYBDENITE.

The molybdenite occurs in one of the aplite dikes, which trends north-northwest and has been traced about 1,500 feet southward from the brink of the gorge of Santa Maria Creek, on whose south wall it is exposed. Its width varies from less than 50 to about 200 feet. The molybdenite is very unevenly distributed through the rock. The greater part of the dike is barren or nearly so, but the mineral is conspicuous in the few shallow cuts and pits lying

between the road and the top of the hill to the south that constitute the only developments on the prospect. The aplitic matrix of the molybdenite is here of uneven texture; its greatest part is of medium grain, but it is interspersed with irregular masses, a few inches in diameter, that are coarser, like pegmatite. Quartz, partly reddened with iron oxide, is especially abundant in the pegmatitic bodies, and it is these bodies that contain the molybdenite.

This mineral is strongly characterized by its lead-gray color, metallic luster, and flexibility, and by its softness, which is such that it marks paper like a lead pencil. It forms more or less imperfect isolated crystals, some of which approximate hexagonal tablets in form. The crystals rarely exceed half an inch in diameter. The sulphide appears to be unaltered, as a rule, a few feet beneath the surface, although in the northernmost opening, a trench in a crushed zone that cuts across the dike, there has been some alteration to molybdite (hydrous ferric molybdate), which has partly replaced molybdenite and has tinged the rock with greenish yellow. At the surface of the outcrops the aplite contains numerous little cavities which are not found in the freshest rock taken a few feet below the surface and which appear to have been left on the removal of the molybdenite by weathering. On the other hand, molybdenite is frequently found in the rock at the very surface.

The molybdenite is clearly an original constituent of the aplite, to which it is confined. Its occurrence in the coarser parts of the rock indicates that the coarse crystallization and the mineralization were both due to local concentration in the magma of the more mobile constituents. To its mode of origin is due its uneven distribution.

A large sample of the rock is said by the owners to have assayed about 2 per cent of molybdenite. Although the Geological Survey has made no assay of the material, it may safely be said, as a result of the field examination, that very little, if any, of the aplite contains as much as 2 per cent of molybdenite. The dike is for the most part barren or nearly so, and its tenor as a whole can not exceed a small fraction of 1 per cent. A bulletin of the Bureau of Mines giving the results of quantitative tests of this ore, as well as of a great number of others, is now in press.¹

POSSIBLE FUTURE DISCOVERIES.

The possibility of further discoveries of molybdenite near Ramona deserves consideration. A few hours was devoted to an examination of three other dikes that crop out within view of the prospect in positions indicated on the map (fig. 11). No molybdenite was found, but in places the occurrence of cavities that resemble those left by the

¹ Horton, F. W., Molybdenum, its deposits and uses: Bur. Mines Bull. 111 (in press).

removal of molybdenite suggest that the mineral may be present a few feet beneath the surface. There was little evidence that any of the dikes examined contains the mineral abundantly. It is possible, however, that workable deposits may be found in some of the many similar dikes that rib the neighboring hills. The quest for such deposits would be less difficult than most prospecting, for the dikes are easily followed, and the presence of molybdenite at any point where indications of it appeared to exist could usually be verified or disproved by making a shallow excavation. Small cavities in the rock, the greenish-yellow stain due to molybdite, and particles of molybdenite itself are among the indications to be looked for.

It is not certain that the ore would everywhere be confined to aplite. Molybdenite inclosed in granite is said to have been discovered between Ramona and Foster.

It may not be amiss to warn prospectors against oversanguine estimates of the richness of any deposits that may be found. Molybdenite is a mineral that makes a strong showing because of its bright metallic luster and its general occurrence in broad, thin flakes. Because of this prominence and because of its comparatively low specific gravity (4.7 to 4.8) its abundance in a rock is likely to be much overestimated when judged by the eye alone.

AN OCCURRENCE OF NICKEL ORE IN SAN DIEGO COUNTY, CALIFORNIA.

By F. C. CALKINS.

INTRODUCTION.

As no ores are mined for nickel at present within the United States, a peculiar interest attaches to deposits that hold out some promise of being valuable primarily for their nickel content. A hasty visit to such a deposit in San Diego County, Cal., was made by the writer in December, 1915.

The deposit is the property of the Friday Copper Mining Co., in which Beecher Sterne, of San Diego, is one of the principal owners. It lies near the main highway about 4 miles south of Julian, a village about 60 miles northeast of San Diego, with which Julian is connected by two or three automobile stage lines.

The Friday claim was located about 30 years ago, in the belief that it contained a vein of copper, and owing to the slowness with which development went forward the nickeliferous character of the ore was not discovered for some years. It is worth remarking that the famous Copper Cliff mine, at Sudbury, Ontario, and the Gap mine, in Lancaster County, Pa., had in this respect a similar history. The workings at present consist of a shaft about 250 feet deep and several drifts. The drifts at about 200 and 250 feet from the surface are each about 200 feet long; the others, which are shorter, are blocked by rock falls.

GEOGRAPHIC AND GEOLOGIC CONDITIONS.

The Julian district lies in the heart of a zone of not very rugged mountains for which no general designation is in popular use, but which it seems proper to consider as part of the peninsular range that forms the backbone of Lower California. The west base of this range lies a few miles east of San Diego. Julian is near the divide between the Pacific and Salton Sea, at an altitude of about 4,200 feet above sea level; some of the neighboring summits rise rather gradually to altitudes exceeding 5,000 feet. The climate at

these altitudes is sufficiently cool and moist to favor the general growth of an open forest of oaks and pines, from which a supply of mine timber may be derived. Some of the slopes, however, are covered with dense brush. Although the district is remote from railways, it is favored by fairly good roads and by cheap automobile transportation.

The rocks that form the mountains about Julian and west of it are chiefly igneous. From the west foot of the range to a point some distance east of Ramona they are almost exclusively granitic. Farther east metamorphosed sedimentary rocks form considerable areas, though they remain subordinate to the igneous intrusives, which, between Ramona and the Friday mine, are chiefly granodiorite or diorite.

In the immediate vicinity of the mine occurs a body of igneous rock, unlike any that was noted to the west, whose area of exposure is strongly characterized by a rusty-red soil, interspersed with bowlders and small outcrops of dark rock. Broken surfaces of fresh rock reveal a greenish-gray medium-grained crystalline mixture of several minerals. Feldspar is subordinate to dark silicates, of which olivine is shown by the microscope to be the chief, accompanied by pale amphibole and by augite or diallage. The rock may be classified as amphibole-bearing olivine gabbro, though the specimen examined verges closely on peridotite because of the subordination of its feldspar. The olivine in a specimen taken from the immediate vicinity of the ore body is remarkably fresh. A minor constituent of special practical interest, because it forms the greater part of the ore, is pyrrhotite, small grains of which are sprinkled evenly through the rock.

The gabbro at the mine is in contact with a dark-gray fine-grained mica schist, evidently derived by metamorphism from a clay shale. The dip of the schist layers, in the few places where it has been observed, is steeply southward. Very little was learned, in the brief time available, concerning the form and extent of the gabbro mass. Its area appears to be at least a square mile and may be many times as much. The surface of its contact as exposed in the mine workings is steep in general but irregular in detail and is partly determined by faults.

ORE BODY.

MINERAL COMPOSITION.

The ore of the Friday property consists mainly of pyrrhotite but contains pyrite, chalcopyrite, and an iron-nickel sulphide and is accompanied by small quantities of amphibole and of a carbonate that is probably calcite. When the ore is viewed with the naked eye,

pyrrhotite alone is conspicuous. The pyrrhotite possesses an unusually perfect cleavage, or parting, which shows that some crystal individuals are as much as 2 inches in diameter. The other sulphides are better discerned on polished faces, particularly on those that have been etched for a few minutes with boiling hydrochloric acid ($\frac{1}{2}$), which corrodes and darkens the pyrrhotite, to which the other minerals, remaining bright, then present a contrast, while they also differ in color from one another. Pyrite, which presents a somewhat rough brass-yellow surface, occurs in a proportion estimated to exceed 10 per cent. It forms a very irregular network and has clearly originated through the replacement of the pyrrhotite by solutions or gases (perhaps H_2S) that have permeated a multitude of fractures. Much less abundant are chalcopyrite, which is bright in luster and deep-yellow in color, and a smoothly polished silvery white mineral whose identity is not quite certain. This mineral has been shown by chemical test to be a sulphide of nickel and iron, but its crystal system could not be ascertained. It is altogether free from the tinge of brownish yellow that characterizes pentlandite. It differs from gersdorffite ($NiAsS$) in its freedom from arsenic and in its lower degree of hardness. It seems most likely to be polydymite (Ni_4S_5 , with iron replacing part of the nickel, or $Ni_3Fe_2S_5$).

The cupriferous and nickeliferous sulphides occur for the most part in contact with each other and form together irregular bodies about 5 millimeters in maximum diameter, which exhibit some tendency to alignment; the supposed polydymite also forms thin veinlets cutting pyrrhotite but not pyrite. The age relations of the minerals are not quite clear. The phenomena suggest that the cupriferous and nickeliferous sulphides are nearly contemporaneous and older than the pyrrhotite, though some of the nickeliferous mineral appears to have been redeposited in fissures. The pyrite is pretty plainly the latest of the sulphides, though it has replaced the pyrrhotite alone without penetrating the others.¹ Scattered grains of amphibole and of chlorite are inclosed in the sulphides, and all the minerals are cut by a network of calcite veins. Both the silicates and the carbonate are best observed in thin section.

The fresh sulphides were found only at considerable depth below the surface. The outcrop of the vein is a spongy gossan consisting chiefly of limonite, and a small amount of material rich in malachite was found between this and the unoxidized ore. Oxidation, which is perhaps especially favored by the closely spaced partings in the

¹ The order pyrite, pyrrhotite, pentlandite, chalcopyrite was observed in ores from Sudbury and elsewhere by William Campbell and C. W. Knight (On the microstructure of nickeliferous pyrrhotite: *Econ. Geology*, vol. 2, p. 350, 1907). On the other hand, A. L. Du Toit (Report on the copper-nickel deposits of the Jusizwa, Mount Ayliff, East Grinqua-land, Cape of Good Hope: *Geol. Comm. Ann. Rept.*, vol. 15, p. 110, 1910) found the sequence chalcopyrite, pentlandite, pyrrhotite.

pyrrhotite, attacks vigorously the ore thrown on the dump and develops enough heat to char wood. Its chief products, in the first stage, are sulphates, which are readily dissolved, so that much of the nickel and copper must have been lost from the accumulated ore.

The ore can not be said to have a gangue in the proper sense of the term. The minerals intimately mingled with the sulphides are almost negligible in quantity, though the ore is more or less mingled with country rock at the margins.

TENOR.

No assays or chemical analyses of the ore have been made by the Geological Survey, but several have been supplied by the company. These, on their face, indicate a wide variation in the nickel content,

the percentages reported ranging from 2.94 to 22.95. The higher figures, however, are not confirmed by the appearance of the ore that was examined. It seems, on the other hand, as if considerable reliance might be placed on the figures given in two fairly detailed analyses by well-known eastern firms, namely, 4.34 and 4.12 per cent. Both these analyses report gold and silver to

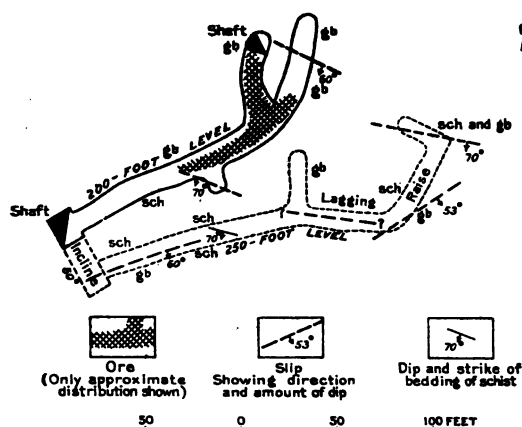


FIGURE 12.—Sketch map of principal workings of Friday mine, near Julian, San Diego County, Cal. gb, Gabbro; sch, schist.

be absent, though the assays giving the highest figures for nickel report them as present in weighable amounts. Copper, according to the assays, ranges from a trace to 2.4 per cent. Platinum, whose possible presence in traces at least is suggested by the geologic relations of the ore, apparently has not been looked for.

FORM AND RELATIONS.

Regarding the form of the ore body and its detailed relations to the country rock, only partial evidence was gathered by examination of the one accessible drift in which the ore is exposed. Its observed distribution is rudely indicated in figure 12, though some portions of it may have been overlooked. The observations indicate that the ore forms a chimney-like body of steep inclination, partly bounded by slips. The mass does not appear to be sharply defined except where there is indication that it is faulted. It lies near the contact of gab-

bro and schist but is partly inclosed in gabbro. It is cut by a thin dike of pegmatite containing conspicuous crystals of common black tourmaline.

The lowest drift, which follows a zone of fissuring, has failed thus far to uncover the ore, which appears to have been cut off by some of the fissures that are followed or crossed by the drift. As these dip steeply southward, it seems probable, inasmuch as the majority of steep faults are normal, that the ore is to be looked for at a greater depth on the south side of the zone of fissuring.

PROBABLE ORIGIN.

By its mineral constitution and its geologic situation at the contact of a basic intrusive rock with older sediments, the Friday ore body belongs to the numerous class of nickeliferous deposits, of which the Sudbury district of Ontario¹ contains the most noted and productive examples. The deposits at Sudbury are regarded by the authorities most familiar with them as having been formed by gravitative concentration from a molten magma. A huge blister-like body or laccolith many miles in breadth, of norite, a rock that is closely related to gabbro, was injected at the base of a series of horizontal strata. As the magma gradually crystallized, particles of sulphides were formed all through it and, by reason of their heaviness, sank in great part to the floor of the magma chamber before their settling was finally arrested by solidification of the cooling magma. The norite laccolith was afterward bent or subsided in the center, so as to take the form of a spoon, and its edges were exposed by erosion, so that the ore bodies became accessible. Those of simplest character, which appear to be the direct result of settling, dip toward the center of the spoon. Their lower sides, in contact with the floor of the laccolith, are sharply bounded, but their upper sides grade into the norite, which, like the gabbro of the Friday mine, contains visible particles of pyrrhotite. Besides these simple marginal deposits, there are others complicated by faulting and by redeposition of the ores, and there are also "offset" deposits lying entirely without the main body of norite.

The data obtained by a brief examination of the Friday mine are hardly sufficient in themselves to establish clearly the nature of its ore body, but the resemblance of this body in some essential features to those at Sudbury suggests a similarity of origin. The igneous origin of the Friday ore is strongly indicated by three outstanding facts. First, the penetration of the ore by pegmatite shows that ore deposition was completed before the close of igneous activity. Second, the deposit differs from those of secondary origin by the total

¹ Coleman, A. P., The nickel industry, with special reference to the Sudbury region, Ontario: Canada Dept. Mines, Mines Branch, 1913.

absence of contemporaneous gangue minerals, such as quartz and calcite; the small amount of carbonate found in the ore, being of later deposition, has no bearing on its origin. Finally, pyrrhotite, the principal constituent of the ore, occurs in the gabbro close to the ore body in association with perfectly fresh olivine. If the sulphides had been deposited from solutions, these solutions would certainly have attacked that very unstable silicate.

FUTURE DEVELOPMENTS.

A suggestion has already been ventured (p. 81) regarding the direction in which the ore body is to be looked for in depth, on the assumptions that it actually persists downward and is normally faulted. When it is considered, however, that either or both these assumptions may be erroneous, and that the ore body, being probably igneous, is likely to be irregular in form, the risk of wasting effort in unsuccessful exploration appears rather greater than usual. This argues, to some extent, in favor of exploration by the diamond drill, a method that is much employed in the Sudbury district.

It is possible that the surface in the Julian district, where prospectors have been accustomed chiefly to search for gold, has not been thoroughly prospected for the nickeliferous deposits. Search for outcrops of gossan along the margins of the gabbro mass might be rewarded by further discoveries.

A word, finally, should be said in favor of shielding ore dumps, so far as possible, from moisture, whose decomposing action may finally reduce the ore to worthless limonite.



DEPARTMENT OF THE INTERIOR

FRANKLIN K. LANE, Secretary

UNITED STATES GEOLOGICAL SURVEY

GEORGE OTIS SMITH, Director

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LODE MINING IN THE QUARTZBURG AND
GRIMES PASS PORPHYRY BELT
BOISE BASIN, IDAHO

BY

E. L. JONES, JR.

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LODE MINING IN THE QUARTZBURG AND GRIMES PASS PORPHYRY BELT, BOISE BASIN, IDAHO.

By **E. L. JONES, Jr.**

INTRODUCTION.

FIELD WORK AND SCOPE OF REPORT.

This report is based on a reconnaissance trip to the Boise Basin from July 10 to July 12, 1915, by the writer, with J. B. Umpleby, under whose direction this work was undertaken, and on an examination by the writer, during September, 1915, of the geology and ore deposits of the basin. The publication of a report on the Quartzburg and Grimes Pass porphyry belt in advance of the report on the ore deposits of the State by Mr. Umpleby is considered advisable because of the recent important mining developments along this belt and because of frequent requests for information concerning the Boise Basin and vicinity which can not be met because the stock of the previous Survey report on this region has been exhausted. Although this paper takes up in detail only the Quartzburg and Grimes Pass area it gives a brief account of the geology and ore deposits of the Boise Basin as a whole.

ACKNOWLEDGMENTS.

The mining men of the Boise Basin extended many courtesies to the writer, who makes grateful acknowledgment, particularly to Messrs. Etheridge Walker, E. E. Carter, E. F. Blain, F. T. Day, A. C. Gallupe, and E. R. Abernathy.

PREVIOUS WORK.

The geology and ore deposits of the Boise Basin were studied by Lindgren¹ in 1896, and his important contribution will be referred to frequently. The geologic map that accompanies the present report is a reproduction of Lindgren's map drawn to a smaller scale on parts of the Survey's reconnaissance topographic maps of the Idaho Basin and Garden Valley quadrangle and the more detailed map of the Boise quadrangle. On the map in this report (Pl. II) the locations of the principal mines in the Boise Basin are shown by mine symbols and numbers.

¹ Lindgren, Waldemar, The mining districts of the Idaho Basin and the Boise Ridge, Idaho: U. S. Geol. Survey Eighteenth Ann. Rept., pt. 3, pp. 617-744, 1898.

LOCATION.

The Boise Basin, which lies in Boise County, Idaho, is an intermontane depression near the western edge of the mountainous region that occupies the central part of the State. The Boise Basin is separated from the Snake River plains on the west by Boise Ridge; the low-lying divide between Payette River and Moore Creek is its northern boundary; and high mountains flank it on the east and south.

SETTLEMENTS AND ACCESSIBILITY.

Idaho City, Centerville, Placerville, Quartzburg, and Pioneerville are the principal centers of the mining industry. The total population of the Boise Basin is probably not over 700, but in the early days of its mining history the population was many thousands.

All the towns are connected by roads, and several roads lead to outside points. Idaho City, the county seat, is connected with Boise by a stage road 32 miles long that crosses Boise Ridge at an altitude of 5,000 feet. The Hawkins toll road, which crosses this ridge at an altitude of 5,500 feet, is the means of access between Placerville and Horseshoe Bend, on Payette River. From Placerville a road leads north to Garden Valley, on Payette River, and Pioneerville is also connected with Payette Valley by a road over Grimes Pass. East of Idaho City a road crosses the divide between the drainage basins of Moore Creek and North Fork of Boise River and leads to the Edna and Banner silver mines. The Intermountain Railroad, owned and operated by the Barber Lumber Co., has recently been built to the vicinity of Centerville, on Grimes Creek. It gives access to the Boise Basin from the Boise River valley and Moore Creek. Although built primarily for the removal of the valuable timber from tracts in the Boise Basin to the large sawmill at Barberton, the railroad will greatly benefit the mining industry of the basin.

MINING DISTRICTS.

The Idaho City, Quartzburg, Centerville, and Pioneerville (Summit Flat) mining districts center about the towns of the same names. Other mining districts in the Boise Basin are the Gambrinus and Elkhorn districts, northeast of Idaho City. The term "Boise Basin district" is sometimes used to include all these districts.

HISTORY.

The history of quartz mining in the Quartzburg and Grimes Pass porphyry belt is closely associated with the famous placer deposits of the Boise Basin. Placer gold was discovered in this region in August, 1862, by a party of prospectors from Walla Walla, Wash., under the leadership of George Grimes. Grimes was killed by In-

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dians, and his grave is at Grimes Pass, a few hundred feet east of the road that leads to Payette River. The greater part of the placer ground was located in the same year that gold was discovered, and the succeeding years were marked by great mining activity in this and surrounding regions. The placers of the basin have been worked continuously from their discovery to the present time, though the greatest production was made in the first few years of operation. In many places the rich placer ground was traced to the outcrops of decomposed quartz veins, and these veins were early exploited, though the production of the quartz mines has always been less than that of the placers. Many veins worked by mines in the Gambrinus district, northeast of Idaho City, and in the Quartzburg district were thus discovered. In 1867 and 1868 at least 10 quartz mills were reported to have been in operation. These mills treated free-milling gold ores, but after a period of activity and considerable production many of them were dismantled. The cessation of milling in the Gambrinus district and in other parts of the basin was due in part to the working out of ore bodies and in part to the increasing proportion of ores not amenable to the stamp-amalgamation process. Within recent years, owing to the exhaustion of the placer ground, the quartz deposits are receiving more attention, and mill treatment suitable to the base ores of the Quartzburg district has been successfully devised. Near Grimes Pass the Diana Mines Co. has begun the development of a number of properties and has conducted mill experimentation work. The Gold Hill, Mountain Chief, and Golden Age mines, in the Quartzburg and Grimes Pass belt, have produced notable amounts of gold and silver in recent years.

PRODUCTION.

The amount of gold and silver produced in the Boise Basin has long been the subject of dispute, for the records of production for the early years are very incomplete. From the best records available, however, the total production of gold and silver from 1863 to 1914 in Boise County is estimated by the Geological Survey at \$53,096,995. Of this amount probably more than 95 per cent was derived from the Boise Basin.

During the last five years the installation of large electrically driven dredges that work in extensive creek-bed gravels has materially added to the production of the basin, and in 1912, 1913, and 1914 the annual production exceeded \$500,000.

Gold and silver produced in Boise County, Idaho, 1863 to 1914.

Year.	Gold.		Silver.		Total value.
	Quantity.	Value.	Quantity.	Value.	
	<i>Fine ounces.</i>		<i>Fine ounces.</i>		
1863 a	145,125	\$3,000,000	50,000	\$67,250	\$3,067,250
1864 a	193,500	4,000,000	70,000	94,150	4,094,150
1865 a	241,875	5,000,000	80,000	106,960	5,106,960
1866 a	241,875	5,000,000	80,000	107,120	5,107,120
1867 a	208,013	4,300,000	* 70,000	93,100	4,393,100
1868 a	208,013	4,300,000	70,000	92,820	4,392,820
1869 a	145,125	3,000,000	50,000	66,250	3,066,250
1870 a	130,612	2,700,000	40,000	53,120	2,753,120
1871 a	96,750	2,000,000	50,000	66,250	2,066,250
1872 a	48,375	1,000,000	26,000	34,372	1,034,372
1873 a	38,700	800,000	24,000	31,128	831,128
1874 a	33,863	700,000	27,000	34,506	734,506
1875 a	29,025	600,000	30,000	37,200	637,200
1876 a	29,025	600,000	35,000	40,600	640,600
1877 a	24,188	500,000	27,000	32,400	532,400
1878 a	24,188	500,000	27,000	31,050	531,050
1879 a	19,350	400,000	24,000	26,880	426,880
1880 b	37,011	765,086	81,025	93,179	858,265
1881 b	14,513	300,000	23,203	26,219	326,219
1882 b	14,029	290,000	15,469	17,635	307,635
1883 b	27,332	565,000	30,938	34,341	599,341
1884 b	19,350	400,000	30,938	34,341	434,341
1885 b	29,973	619,000	110,702	118,451	738,051
1886 b	18,910	390,904	103,945	102,906	493,810
1887 b	24,296	502,246	139,109	136,327	638,573
1888 b	13,600	283,000	52,246	49,111	332,111
1889 b	13,280	274,522	113,376	106,573	381,095
1890 b	18,695	386,459	89,002	93,452	479,911
1891 b	17,253	356,651	124,325	123,082	479,733
1892 b	18,209	376,413	163,368	142,130	518,543
1893 b	13,547	280,041	28,896	22,539	302,580
1894 b	15,859	327,835	24,876	15,672	343,507
1895 b	16,429	339,617	7,954	5,170	344,787
1896 b	15,770	325,995	4,645	3,159	329,154
1897 b	11,274	233,054	2,811	1,687	234,741
1898 b	10,008	206,884	2,685	1,584	208,468
1899 b	19,055	393,902	5,681	3,409	397,311
1900 b	17,835	368,682	5,068	3,142	371,824
1901 b	18,104	374,243	6,325	3,795	378,038
1902 b	16,481	340,692	4,770	2,528	343,220
1903 c	7,533	155,707	8,432	4,504	160,211
1904 c	14,265	294,884	38,330	21,944	316,828
1905 c	7,360	152,145	1,960	1,184	153,329
1906 c	11,079	229,024	4,909	3,289	232,313
1907 c	11,381	235,276	17,553	11,585	246,861
1908 c	9,641	199,307	7,029	3,725	203,032
1909 c	10,450	216,031	8,484	4,412	220,443
1910 c	9,647	199,430	14,443	7,798	207,228
1911 c	17,099	353,464	7,308	3,873	357,337
1912 c	24,297	502,277	8,753	5,383	507,660
1913 c	29,996	620,070	10,942	6,609	626,679
1914 c	29,084	601,227	13,441	7,433	608,660
	2,460,337	50,859,668	2,092,941	2,237,327	53,096,995

a Estimate of gold by Waldemar Lindgren, U. S. Geol. Survey Eighteenth Ann. Rept., pt. 3, p. 655, 1898, with estimate of silver by C. N. Gerry. Commercial price of silver used throughout.

b Director Mint Repts., 1880 to 1902. Commercial price of silver substituted.

c U. S. Geol. Survey Mineral Resources, 1903-1914.

It is difficult to separate the production of the lode mines from that of the placers, but from the best data available the lode production probably does not exceed \$7,000,000.

MINING CONDITIONS IN THE BOISE BASIN.

Natural conditions are very favorable to mining in the Boise Basin. The heavy forests of yellow pine and fir furnish an abundant supply of lumber for use in building and mining. Commonly the mines are

equipped with sawmills, and sufficient timber can be cut on the mining claims to supply their own demands. Water for milling is abundant, but the supply for hydraulic placer mining is scant, and it must be conducted through ditches and flumes many miles long that are expensive to build and maintain. Most of the hydraulic operators can work only for a few months of the year. The streams in the basin are too small and too low in gradient for the development of electric power, but the Boston & Idaho Co.'s power plant on Payette River supplies power for the company's own needs and sells surplus current to other mines of the region. The Intermountain Railroad, which connects Centerville with Boise, will materially reduce the charges for transportation on mine and mill supplies and on ores and concentrates shipped to smelters.

MILLING PRACTICE.

The future of lode mining in the Boise Basin, particularly along the Quartzburg and Grimes Pass porphyry belt, will largely depend on the adoption of suitable mill treatment, for the ores taken out along this belt are becoming increasingly base, and in general less than 50 per cent of the gold content can be recovered by amalgamation. The present milling practice of the Boise Basin ores is stamp amalgamation, concentration, or cyanidation, or a combination of these processes.

Stamp-amalgamation mills were exclusively used during the early days of mining and are still adaptable to some of the ores in the Gambrinus district, and a large part of the gold content of the Gold Hill ores is obtained by this method. At the Gold Hill mine, however, an additional saving is made on Wilfley tables and vanners. Most of the concentrates from this mine were shipped, but for a time cyanidation of the concentrates proved a success, and it is said that this practice will be resumed. Other ores from the Quartzburg and Grimes Pass porphyry belt are much baser than the Gold Hill ores. The ores from the Mountain Chief mine, at the south end of this belt, are treated by combined amalgamation, concentration, and cyanidation. About 40 per cent of the gold content is caught on the amalgamation plates. The overflow from the plates is concentrated to a low-grade product by Deister and Wilfley tables, and the concentrates are further treated with a weak cyanide solution. In this process 92 per cent of the gold content is extracted. The combined extraction of the processes used at this mine is said to be about 85 per cent. The company is contemplating the cyanidation of the whole mine output.

The Golden Age mill, near Grimes Pass, is now treating base ores from the lower workings. The total saving of the gold content by

combined stamp amalgamation and concentration is said to be only 60 per cent.

A mill was built in 1902 to treat the ores from the Enterprise group. The processes employed, a combination of amalgamation and concentration, are reported to have been not very satisfactory. This mill has been acquired by the Diana Mines Co., and experiments are being made on the ores from that company's numerous claims. Some of these ores are composed chiefly of sphalerite and chalcopyrite.

PHYSIOGRAPHY AND GEOGRAPHY.

From the high ridge above Quartzburg an observer looking eastward obtains a vivid impression of the significant structural features of the Boise Basin. Before him the area of depression, 15 miles long and 12 miles wide, is inclosed on all sides except to the north by high mountains. This area is traversed by heavily wooded flat-topped and gently sloping ridges that rise but a few hundred feet above the stream levels. These ridges, though outliers of the inclosing mountains, are separated from them by abrupt slopes several hundred feet high. This change in slope is well marked on the ridges to the east, though modified by the valleys. The south boundary of the basin is marked by an abrupt change in slope from the level of the benches that border Moore Creek on the south. In a similar manner the Boise Ridge on the west is sharply delimited from its outlying spurs. The ridge that bounds the basin on the north, however, presents no strong contrast to the topography of those within the basin. This ridge, which here marks the divide between Payette River and tributaries of Moore Creek, extends from the Boise Ridge north of Quartzburg eastward around the head of Grimes Creek and joins the high mountains on the east side of the basin. Near Grimes Pass the summit of this ridge is but a few hundred feet above Grimes Creek, but its northern slope is a steep descent of 2,500 feet to the level of Payette River.

The most prominent peaks of the surrounding mountains are Wilson Peak and Elk Creek Mountain, to the east; Thorn Creek Mountain, to the south; and Shafer Butte, on Boise Ridge. Of these peaks Elk Creek Mountain, about 8,300 feet in altitude, is the highest, and Shafer Butte, 7,500 feet, the lowest. Idaho City, at an altitude of 4,000 feet, is the lowest town in the basin. Quartzburg is at an altitude of 4,500 feet, and Pioneerville at about 4,300 feet. Grimes Pass is 5,100 feet above sea level and Garden Valley Pass 4,900 feet.

The Boise Basin is drained by Moore Creek, which joins Boise River about 20 miles southwest of Idaho City. The principal tributaries of Moore Creek are Granite, Grimes, and Elk creeks. Within the basin these streams flow in broad gravel-filled channels with grades as low as 20 feet to the mile, but their upper courses in

the surrounding mountains have steep grades and narrow valleys. Their grades below the basin are also much steeper than those within it. Evidently the peculiar physiographic features of the Boise Basin were not formed by stream erosion alone. An explanation of their origin is given in the discussion of the geologic history below.

GEOLOGY.

ROCKS OF THE AREA.

The Boise Basin is underlain chiefly by granite, but within it there are also later intrusive porphyritic rocks, lamprophyres and pegmatites, small areas of lavas and lake beds, and bench and stream gravels. The granite is part of the Idaho batholith, an intrusive mass whose area exceeds 20,000 square miles. The age of this granite is considered late Cretaceous or early Tertiary. Porphyritic dike rocks, which comprise diorite porphyry, rhyolite, quartz diorite porphyry, and related varieties, are most abundant in the zone extending northeastward from Quartzburg, but rocks of one or more of these types occur sparingly in other parts of the basin. Pegmatites and dark fine-grained dike rocks (lamprophyres) are more generally distributed through the area, and commonly the lamprophyres are intruded in the fissures or shear zones that contain the ore deposits. Small areas of lake beds and associated basalts overlie the granite near Idaho City, Placerville, and Pioneerville. Old bench and stream gravels occur at numerous places along the streams and in the low divides between them. Generally their maximum elevation does not exceed 250 feet above the creek bed, but high on Boise Ridge Lindgren noted a deposit of gravel whose present position can be accounted for only by extensive faulting.

GEOLOGIC HISTORY.

With regard to the geologic history of the Boise Basin Lindgren states:

The succession of geological events to which the existence of the basin and of the gold-bearing gravels is due is neither simple nor easy to decipher. In a large degree this is owing to the very monotonous structure of the bedrock series, which gives few clues, except those indicated by the topography, to the character of the movements that have taken place, for it soon becomes apparent during a study of the district that erosion alone, unaided by orographic movements, can not have produced this depression situated on the divide between two main rivers.

The principal events are believed to be as follows, though the sequence is incomplete:

The oldest rock is the granite, which is of late Cretaceous or early Tertiary age. Next the granitic dike rocks were intruded, and still later the lode deposits were formed. Before the uplift that differentiated the Snake River plains from the mountainous area to the

east the granite was extensively eroded, and the higher summits are thought to be part of the old surface thus produced. The structure of the basin is due to faulting, by which a block of granite was sunk far below the surrounding upland surface. At this time the drainage system was initiated, and the streams within the basin eroded channels nearly to their present levels. Later, during Tertiary time, Snake River was dammed by causes ascribed to crustal movements, and the plains area was occupied by a lake whose high-level mark, as recorded on the mountains near Boise, was 4,200 feet. This lake extended up Boise River and its tributary Moore Creek and occupied much of the basin. Beds of clay and fine and coarse granite sands were deposited in the lake, and gravel deposits were laid down at the mouths of tributary streams. Basalt flows were also intercalated with the lake beds. Further crustal movements caused the draining of the Tertiary lake, and the streams within the basin resumed their erosion. Large parts of the gravel and lake beds within the basin were removed, but further faulting occurred and some blocks of lake deposits were sunk and others tilted to altitudes above that of their original deposition. In late Tertiary time came the eruption of Snake River basalt. On lower Moore Creek lava of this age that probably flowed through a vent along the stream forms a level floor whose top is about 100 feet above the creek. When this lava was poured out it effectively dammed the creek and caused the deposition of gravel along the main streams of the Boise Basin. These gravels are termed bench gravels and occur more or less continuously at elevations ranging from a few feet to 100 feet above the stream beds. The lava barrier was gradually cut through by Moore Creek, and its base is now well above the stream level.

IGNEOUS ROCKS.

GRANITE.

Within the Boise Basin the granite shows little variation in composition and lithologic character. It is a coarse-grained gray rock that readily disintegrates to a coarse sand. It is not well exposed over the larger part of the area, and generally specimens of the fresh rock can be obtained only from mine workings. Quartz, orthoclase, oligoclase, and biotite are the principal constituents. Hornblende is a variable constituent, and where present occurs in small amounts. Titanite and zircon are accessory. The granite generally shows little evidence of secondary structure, but along the Quartzburg and Grimes Pass porphyry belt and in the Gambrinus district the granite is sheared in zones that trend, respectively, northeast and about N. 60° W.

DIKE ROCKS.**GENERAL FEATURES.**

The zone of porphyritic dike rocks in the Boise Basin is over 12 miles long, and extends from Canyon Creek to and beyond Grimes Pass. Its extent east of the Coon Dog group was not determined. Rocks similar to some of those here described occur in the Pearl district, about 20 miles southwest of Quartzburg, in alignment with the basin zone. Lindgren mapped these rocks in the Boise Basin and used the term "porphyrite" to include the several types. The zone varies in width; it is narrowest in the Gold Hill mine, where it is probably not over 200 feet wide, but it is nearly a mile wide at the head of Wolf Creek, gradually narrows to a quarter of a mile at the Golden Age mine, and beyond that attains a width of over a mile.

The dike rocks of the porphyry belt present many variations, and the relations of the different types are not everywhere apparent. Some types occur throughout the zone, but others are only local. In places one type may grade to another type. The rocks of this zone consist of diorite porphyry, quartz diorite porphyry, granite porphyry, rhyolite porphyry, and narrow fine-grained dark dike rocks. The diorite porphyry and the porphyritic granitic rocks are the most persistent. Rhyolite was noted only in the vicinity of Grimes Pass. It is the dominant rock in the Coon Dog No. 1 claim and occurs as a small mass inclosed in diorite porphyry in the Golden Age mine. In common with the granite, the dike rocks are greatly decomposed on the surface and no attempt has been made to map the different kinds.

QUARTZ DIORITE PORPHYRY AND GRANITE PORPHYRY.

Rocks that are best described by the terms quartz diorite porphyry and granite porphyry were noted at several places along the zone from the Gold Hill mine to the claims of the Enterprise group. The relations of these varieties are not clear, though probably they are gradations of the same magma. These rocks are the dominant kinds in the Gold Hill mine, and they appear to be older than smaller masses of diorite porphyry and narrow dikes of lamprophyre. All these rocks are altered, and the alteration is greatest along shear zones containing the ore bodies, where the feldspars are altered to sericite and calcite and the hornblende and biotite are altered to chlorite. Pyrite in cube form is abundant and occurs commonly in the altered feldspars. The rocks in this mine are gray to green. Some of the sections examined microscopically show holocrystalline minerals in the groundmass with large feldspar and quartz phenocrysts. The feldspars are labradorite and in less quantity orthoclase. The alteration products of hornblende and biotite are abundant in the ground-

mass. Other rocks of a light-gray color contain large phenocrysts of altered feldspar and rounded crystals of quartz embedded in a fine-grained or felsitic groundmass. In these rocks the ferromagnesian minerals occur in small amounts.

RHYOLITE PORPHYRY.

Intrusive bodies of rhyolite porphyry were observed in the Golden Age mine and in prospects on the Coon Dog group. The rhyolite porphyry may represent a phase of the granite porphyry and quartz diorite porphyry. It is a light-gray rock in which small crystals of quartz are sparingly distributed in a fine-grained or felsitic groundmass. Under the microscope the groundmass is seen to be composed of feldspar and quartz, in part intergrown, and sparse minute grains of chlorite that are probably altered crystals of hornblende. The feldspar is chiefly orthoclase.

DIORITE PORPHYRY.

Diorite porphyry is abundant in the porphyry belt, being well developed between Canyon Creek and the Gold Hill mine and the dominant rock in the Golden Age mine. It is a gray to green spotted rock in which phenocrysts of feldspar generally about a quarter of an inch in diameter are set in a fine-grained groundmass of feldspar, hornblende, and biotite, or their alteration products. The large feldspars are in part labradorite, some of them wholly or partly altered to sericite and calcite. Hornblende is almost entirely altered to chlorite, and the biotite is partly altered to chlorite and white mica. Labradorite, orthoclase, and a little quartz also occur in the groundmass.

DARK-COLORED DIKE ROCKS.

Small dark-colored dikes (lamprophyres) occur at numerous places in the Boise Basin and commonly are intruded in the shear zones and fissures that contain the ore deposits. They are of different types, but probably the most common variety is one containing black mica or biotite and known as minette.

A typical specimen from the Washington mine, in the Gambrinus district, is a dark-green fine-grained rock containing conspicuous plates of biotite. Under the microscope the groundmass is seen to be composed chiefly of brown hornblende, orthoclase, and sodic plagioclase with interstitial quartz. Magnetite in small grains and crystals is plentiful. Chlorite, calcite, and sericite are abundant secondary products.

Numerous boulders of a fine-grained dark-gray rock that have evidently been derived from dikes in the basin occur in the bench gravels east of Placerville. The rock is a granular aggregate of labradorite laths, hypersthene grains, and a little quartz. Magnetite is

present in numerous small grains, and small crystals of apatite are accessory. This rock is petrographically a norite gabbro.

Diabase dikes in the porphyry belt north of Placerville are reported by Lindgren. In the Mountain Chief mine an altered dark-colored dike as much as 30 feet wide closely follows the shear zone in which the vein was deposited. The dike is evidently earlier than the ore, for the vein occurs on one or both walls of the dike, and in places the dike is shattered and numerous veinlets of quartz and ore penetrate it. This rock appears to be similar to the dike rock occurring in the bench gravels east of Placerville.

PEGMATITE.

Pegmatite dikes occur commonly throughout the basin. Owing to the extensive disintegration of the granite and its similarity to pegmatite composition the pegmatite can not be readily distinguished from it, but in places where the granite bedrock is exposed by placer mining numerous small irregular dikes of pegmatite were noted. These dikes are composed principally of large crystals of quartz and feldspar and plates of mica, but in several of them garnets were noted, and the dikes are believed to be the source of some of the rarer minerals found in the placer deposits. Monazite, bismuthinite, and a radioactive mineral whose composition has not been determined are thought to have been derived from the pegmatite dikes.

BASALTS.

The latest igneous rocks in the Boise Basin are the basalts, of which there are small patches associated with the lake beds near Idaho City. As described by Lindgren, the basalt is a medium-grained dark-green rock, with abundant scattered crystals of greenish-yellow olivine. Under the microscope it is seen to be composed of augite, labradorite, olivine, and small crystals of magnetite. A considerable body of basalt occurs high on Boise Ridge northwest of Quartzburg and is correlated with the basalt accompanying the lake beds.

SEDIMENTARY ROCKS.

PAYETTE FORMATION.

The lake deposits to which the name Payette formation has been given consist of unconsolidated clay, sand, and gravel. They occupy a considerable area on both sides of Moore Creek near Idaho City. There is a small area of similar beds on Muddy Creek about 1½ miles north of Pioneerville, and some granite sand that underlies the bench gravels on Fall Creek west of Placerville is thought to be part of this series. About 300 feet of these beds are exposed near Idaho City, where they consist chiefly of green and gray clays with sandy layers

and thin beds of coaly material. On Muddy Creek carbonized wood from the lake beds is used for blacksmith fuel. Silicified wood is commonly found in these beds, and the clay layers contain well-preserved vegetable remains, by means of which the early Tertiary (Eocene)¹ age of these beds was determined. Near Idaho City the beds have a westerly dip as high as 15° and have clearly been disturbed since their deposition. The lake beds are separated from the granite by faults near Warm Springs² and on Elk Creek at the north end of Gold Hill. These faults have preserved the lake beds from erosion; indeed, near Idaho City the lake beds extend far below the present stream channels. A bore hole was sunk in these beds at Idaho City from a point 20 feet above the level of Moore Creek, and a thickness of 516 feet was measured to granite bedrock. The total thickness of lake beds at Idaho City is about 850 feet.

TERTIARY STREAM GRAVELS.

Deposits of auriferous gravels overlie the lake beds east of Idaho City and the granite in scattered areas on ridges near Placerville and Pioneerville. They occur generally not more than 250 feet above the stream levels, and their maximum thickness is about 100 feet. These gravels are regarded by Lindgren as having been laid down soon after the deposition of the lake beds, and are therefore of Tertiary age. They have been worked since the discovery of gold in the basin and are well situated for hydraulic mining, which is the method generally employed. The working season is dependent on the water supply and generally does not exceed three months.

BENCH GRAVELS.

In addition to the Tertiary stream gravels there are in numerous localities along the streams, generally at lower elevations, other gravels that are regarded by Lindgren as having been deposited when lower Moore Creek was dammed by a basalt flow. These gravels are, as a rule, not more than 25 feet thick. West of Placerville, between Fall and Canyon creeks, they are in places 200 feet above the stream levels. Their present position is due, according to Lindgren, to displacement along the steep eastern fault scarp of Boise Ridge. In this connection Lindgren noted on Boise Ridge at an altitude of 6,800 feet a small body of gravel intercalated in basalt flows. The bench gravels have been extensively mined, and little of the original deposit remains.

¹ Knowlton, F. H., Fossil flora of the John Day Basin, Oreg.: U. S. Geol. Survey Bull. 204, pp. 110-111, 1902.

² Lindgren, Waldemar, op. cit., p. 667.

RECENT STREAM GRAVELS.

The major streams within the Boise Basin proper flow in comparatively broad gravel-filled channels with low gradients, in contrast to their upper and lower courses outside of the basin, where the canyons are narrow and the stream grades are steep. The gravel deposits in these channels are in part reconcentrated older stream and bench gravels. Near Idaho City, on Moore and Elk creeks, the average width of these gravels for a distance of 3 miles is about 1,000 feet and their depth ranges from 15 to 30 feet. Tailings from placer operations in the older and higher gravels have spread out over the adjacent creek bottoms and in many places form extensive deposits several feet thick. These gravels were rich in gold and were extensively worked in the early days of placer mining, but owing to the low stream gradients and to the depth of gravel below water level a considerable part of the deposits could not be worked until their systematic exploitation was undertaken by dredges. Below Centerville, on Grimes Creek, to the junction with Granite Creek and up Granite Creek for several miles the creek gravels are available for dredging, but the Moore Creek deposits have been practically worked out.

ORE DEPOSITS.

CLASSIFICATION AND DISTRIBUTION.

The ore deposits of the Boise Basin comprise veins and placer deposits. The veins occur in zones of sheeted granite. The two most persistent zones are the Quartzburg and Grimes Pass gold belt and that in the Gambrinus district, 6 miles northeast of Idaho City, but scattered quartz veins and shear zones occur outside of these main zones. The Quartzburg and Grimes Pass belt extends in a northeasterly direction and bounds the Boise Basin on the northwest; the zone of shearing in the Gambrinus district trends about N. 60° W. and lies partly along the base of the steeper mountains that bound the basin on the east. Both belts are believed to lie in or parallel to zones of major faulting which in part determined the topographic features of the basin.

GAMBRINUS AND ELKHORN DISTRICTS.

Many mines in the Gambrinus district were considerable producers in the early days of mining in the basin, among them the Illinois, Lucky Boy, Gambrinus, Washington, Sub Rosa, Boulder, and Forest King. The Elkhorn mine, in the Elkhorn district, which bounds the Gambrinus district on the north, was extensively worked in 1867 and 1868, and intermittently since then, and is credited with a production of \$800,000. The records of production of these mines are very

incomplete, but it is believed that the Gambrinus and Elkhorn districts have produced not less than \$2,000,000. Most of the mines have not been worked for many years, and their workings are inaccessible. The Lucky Boy mine, however, was being reopened at the time of the writer's visit, and preparations were being made to mill the ore. The ore of the Gambrinus district was largely free milling, and much gold was obtained from sluicing the vein outcrops. Gambrinus, Illinois, and other gulches that head in this belt were very rich in placer gold. The ore is contained in extensive shear zones in granite and is largely oxidized, but it is said that in the deeper workings of the Gambrinus mine stibnite was found, and ores from the Boulder mine contain pyrite, arsenopyrite, and sphalerite. The ore of the Lucky Boy, which is probably similar to ores from adjoining properties, is a sheeted granite traversed by iron-stained seams and by stringers and lenses of quartz, making in places shoots of high-grade gold ore. The Washington mine, in addition to gold ore in shear zones, contains a well-defined vein that is valuable chiefly for silver. Notwithstanding the considerable production of gold from these mines and from placers below them, the exploitation of mines and prospects in the Gambrinus and Elkhorn districts appears to be unaccountably small.

PLACER DEPOSITS.

The placer deposits are found chiefly along the major streams of the basin and in the tributary streams and gulches which head in the gold-belt areas. Fall, Granite, Wolf, Ophir, Muddy, and Grimes creeks and California and Ophir gulches, which head in or cut through the Quartzburg and Grimes Pass belt, and Elk and Moore creeks with their tributaries, which drain the area of the Gambrinus and Elkhorn districts, are all rich in placer gold, while streams outside of these zones and not cutting isolated veins contain little gold. The gold is contained in the older stream and bench gravels and in the recent stream gravels. The principal placer operators of the Boise Basin during the season of 1915 were the Boston & Idaho Gold Dredging Co., operating a dredge on Moore Creek, near Idaho City; the Boise Basin Improvement Co., hydraulicking the old stream gravels of Gold and East hills, near Idaho City; and others conducting hydraulic operations on the Leary-Brogan and Reid tracts, east of Placerville, and on the tracts owned by the Missouri Mining Co., on Muddy Creek.

Coarse gold is becoming increasingly rare in the Boise Basin, as the shallower and richer deposits toward the source of the gold have been worked over. Few of the particles now obtained are worth more than a fraction of a cent, although nuggets worth several dollars are occasionally saved. The placer gold ranges in fineness from 0.770 to 0.912, and is generally of higher grade than the average obtained

from the lodes. The minerals associated with the gold in the placer deposits are monazite, garnet, hematite, ilmenite, bismuthinite, and a rare mineral not specifically determined, which gives a test for radium. Monazite is abundant and widely distributed in the gravel deposits. According to Lindgren, it contains about 1.2 per cent of thorium, one of the principal rare-earth oxides that are used in the manufacture of incandescent mantles. The principal supply of monazite comes from Brazil, where the mineral is of higher grade than the Boise Basin monazite and is cheaply mined. A mill was built near Centerville to save the monazite, but it burned down several years ago, and apparently little of the product was shipped. Small crystals of bismuthinite, or bismuth sulphide, occur sparingly in the Leary-Brogan and Reid tracts, east of Placerville. The rare radium-bearing mineral was noted only at one place in shallow placer ground in a small gulch tributary to Grimes Creek about $1\frac{1}{2}$ miles southwest of Pioneerville. Garnet, hematite, and ilmenite are commonly associated with the placer gold but have no economic importance.

QUARTZBURG AND GRIMES PASS GOLD BELT.

DISTRIBUTION AND CHARACTER OF VEINS.

The Quartzburg and Grimes Pass gold belt contains mines and prospects from the Mountain Chief mine to Grimes Pass, but for a distance of several miles northeast of the Mineral Hill prospect little development work has been done. The veins comprise quartz-sulphide fillings with well-defined walls and narrow veinlets in shattered zones in the country rock. Some of the veins or fissures have a proved length of 1 mile, but their extent in depth has not been determined. The deepest shaft is that of the Gold Hill mine, 500 feet deep, and it represents the greatest depth to which any of the veins have been explored—about 4,000 feet above sea level. The divide between Canyon and Fall creeks at the point where it is crossed by the Mountain Chief vein is about 6,000 feet in elevation; therefore a vertical range of at least 2,000 feet in the vein occurrence is represented. The Gold Hill mine is the only one in which extensive development work has been done, and the exploitation of veins along this belt, like that in the Gambrinus district, is comparatively little. The veins trend in a general northeasterly direction and dip 30° – 80° SE. They are usually in or adjacent to the intrusive porphyries, but some are in granite half a mile from the porphyry contact. In its greatest development near Garden Valley Pass and east of Grimes Pass the vein zone is $1\frac{1}{2}$ miles wide, but southwest of the Gold Hill mine, where the porphyry belt is narrow, the veins are limited chiefly to the footwall of the dike.

MINERALOGY

The primary ore minerals that were observed in the ores of the Quartzburg and Grimes Pass belt are native gold, pyrite, galena, sphalerite, chalcopyrite, stibnite, and tetrahedrite, and those derived from the alteration and oxidation of the primary minerals are cerusite, chalcocite, malachite, and native copper. The zone of oxidation, however, extends only a short distance below the surface, and the secondary minerals form no well-defined deposits and nearly everywhere are associated with some unaltered sulphide material. Native copper was noted in a specimen of finely brecciated rhyolite obtained near the surface on the Coon Dog No. 1 claim, and malachite in surface croppings of granite porphyry on the same claim. Chalcocite occurs as a sooty coating and partial replacement of the chalcopyrite in the Coon Dog ores. Cerusite occurs sparingly as a partial alteration product of galena in shallow ores in the Golden Age, Enterprise, and other workings near Grimes Pass.

The mineral composition of the veins along this belt is variable. Pyrite and sphalerite are most widely distributed; some of the other minerals occur only here and there. Thus massive arsenopyrite was noted only in the deeper workings of the Mountain Chief mine. Stibnite is common in the Mountain Chief and Gold Hill ores. Tetrahedrite occurs chiefly in the ores in the vicinity of Grimes Pass but was also noted in specimens from the Carroll mine. Chalcopyrite is particularly abundant in the ores of the Coon Dog group and occurs sparingly, intergrown with arsenopyrite, in the Mountain Chief ores. Galena is most abundant near Grimes Pass.

Up to the present time gold is the principal metal that has been derived from the mines along this belt, mainly because it predominates in the Gold Hill ores, but silver is also of value in the recently developed Mountain Chief and Golden Age mines, and assays of the ores from several prospects of the Diana Mines Co. indicate high silver contents. The proportion by weight of silver to gold in the Mountain Chief ores is 4 to 1. With the erection of adequate concentrating machinery lead, copper, and possibly zinc will add materially to the metal output of the Grimes Pass ores. Gold is particularly associated with stibnite in the Gold Hill and Mountain Chief ores. In the Gold Hill mine it can frequently be seen, in places in coarse flakes, but in the Mountain Chief mine it is generally not visible until the crushed ore has been scoured in the pan. Some galena ores near Grimes Pass carry high gold contents, and it is reported that large pieces of intergrown galena and gold were obtained from the disintegrated outcrop of the vein on the Overlook claim of the Diana Mines Co. Silver appears to accompany the antimonial minerals, particularly tetrahedrite and also galena.

MINES.

MOUNTAIN CHIEF.

The Mountain Chief mine (No. 11),¹ at the southwest end of the porphyry belt, is $3\frac{1}{2}$ miles west of Placerville. Six claims and one mill site form the group, which is owned by the National Mining & Development Co. The Ebenezer, an adjoining claim, one of the early discoveries of the region, was acquired by the company and is included in the group. The claims extend from the summit of the divide between Fall and Canyon creeks to Canyon Creek. The Mountain Chief and Ebenezer claims produced considerable gold in the early days, mostly from sluicing of the disintegrated vein, but other than \$15,000 reported in the Mint records the amount is not known. The National Mining & Development Co. was organized in 1911, and development work was begun in December of that year. The mill was put into operation October 1, 1912, and continued until May 1, 1913, but since that time it has been running intermittently. The production by the present company is between \$150,000 and \$175,000.

The property is developed by four tunnels, all driven northeastward on or near the strike of the vein. Tunnel No. 1 is near the summit of the divide between Fall and Canyon creeks. Tunnel No. 2 is about 120 feet below No. 1 and is 600 feet long to the face. Tunnel No. 3 is 115 feet below No. 2 and is 800 feet long. Tunnel No. 4 is 168 feet below No. 3 and at the time of visit had been opened for 400 feet. The portal of tunnel No. 4, 5,600 feet in altitude, is several hundred feet above Canyon Creek. Practically all the ore above tunnel No. 3 to the end line of the claim has been stoped out. The ore is conveyed to the mill on Canyon Creek by an aerial tram, the upper terminal of which at the time of visit was being changed from tunnel No. 3 to the portal of tunnel No. 4.

The vein is a fissure filling in sheared granite and diorite porphyry. It strikes N. 45° E. and dips 60° SE. The diorite porphyry occurs at the northeast end of the claim. The shear zone is followed persistently on the hanging wall of the vein by a fine-grained greenish dike rock 10 to 30 feet wide. The rock is considerably altered, but it probably belongs to the lamprophyre group. Dikes of similar character were noted in surface workings of the Ebenezer claim. In No. 4 level the vein or ore shoot is followed by an altered green dike from a few inches to several feet wide. The dike is older than the vein, for the ore may be on either or both walls of the dike or may occur in it as veinlets penetrating shattered parts. The vein or the mineralized part of the shear zone averages 2 feet wide, but it pinches and swells and in places is but a few inches wide. The

¹ The numbers in parentheses indicate corresponding numbers on Plate II.

ore is obtained mainly from a single vein, but here and there sulphide veinlets lead off into the wall rock. The vein varies in character; in some places sulphides with subordinate quartz constitute the fissure filling; in other places coarsely granular quartz is abundant, particularly in the central part of the vein. The sulphides are pyrite, sphalerite, arsenopyrite, chalcopyrite, and stibnite. Stibnite occurs in the quartz-sulphide ore as thin spindles between the quartz crystals or extending across the vugs in the quartz. Ore of this type contains much gold. Sphalerite was particularly abundant in the upper workings, where the wall rocks are of diorite porphyry, but occurs sparingly in the quartzose ores from the lower levels. Massive sulphide ore from the dump of tunnel No. 4 shows an intergrowth of arsenopyrite, pyrite, chalcopyrite, and a few quartz crystals. Arsenopyrite was noted in no other mine along the porphyry belt, although this mineral is common in the ores of the Pearl district. A polished section across quartzose ore shows deposition of pyrite along the walls and granular quartz and small fragments of altered wall rocks in the center. The quartz was deposited at different periods, for the vein shows several bands separated by streaks of small fragments of wall rock. Stibnite and some pyrite occur in the interstices of the quartz crystals. The vein, then, was first composed of pyrite and probably other sulphides, the fissure was reopened by subsequent movement along it, and quartz and finally stibnite were deposited.

Two ore shoots have been developed in tunnels No. 3 and No. 4, and the shear zone connecting them contains small stringers and bunches of ore. According to Mr. Gallupe, the shoot at the southwest end of the workings is 150 feet long and that at the northeast end 400 feet long. Both ore shoots pitch northeast. The assay value of the ore is said to average more than \$30 a ton and is seldom as low as \$20 a ton. Picked ore that showed abundant stibnite assayed more than \$1,000 a ton. In a recent communication Mr. Gallupe states that the ore from the more recently developed parts of tunnel No. 4 assayed from \$30 to \$40 in gold and 6 to 8 ounces of silver to the ton. The vein is 10 inches to 2 feet wide.

The mill began the treatment of ores October 1, 1912. A combined stamp-amalgamation and concentration process was first used. The concentrates were shipped to smelters near Salt Lake City. In August, 1914, cyanidation was employed on the concentrates, with results so satisfactory that the company is planning to work the entire mine output by this method. The mill is equipped with five stamps and its capacity is 20 tons a day. The ore is crushed to pass a 20-mesh screen and flows over plates, where approximately 40 per cent of the gold content of the ore is caught. The overflow from the plates is classified and treated on tables where a low-grade concen-

trate is obtained. The concentrates are reground in a 4-foot pan to a slime and then treated with a weak cyanide solution—2 pounds cyanide to the ton of water. The charge is agitated for 48 hours and subjected to intermittent decantation. An extraction of 92 per cent of the gold content of concentrates is made, and the combined recovery by amalgamation and cyanidation is 85 per cent. The fineness of the bullion is slightly more than 0.600.

BELSHAZZAR.

The Belshazzar group (No. 12) of eight unpatented claims joins the Mountain Chief group on the northeast and extends to Fall Creek. George Tew, Lewis Klein, and associates are the owners of the property. The discovery was made in 1875 through placer workings, and the disintegrated vein matter near the divide between Fall and Canyon creeks is said to have yielded \$65,000 in gold. There has been intermittent development on the property since 1880, but the last productive work was done in 1909. About 4,000 tons of ore has been treated in a small stamp and concentration mill on the property, and the average value of the ore was \$10.48 a ton. Fully 50 per cent of the gold content of the ore was recovered on the plates. The concentrates, which are mainly pyrite, assay from \$21 to \$100 a ton, but they have not been shipped.

The mine is developed by three tunnels at intervals of 100 feet on the dip of the vein. The upper tunnel is driven 550 feet, the middle tunnel 600 feet, and the lower tunnel 512 feet. They are connected by raises. From the lower tunnel an aerial tram conveys the ore to the mill on Fall Creek, 400 feet below. The vein, which on its continuation in the Mountain Chief group strikes N. 45° E. and dips 60° SE., on this group strikes N. 60°–80° E. and dips at an average of 35° S., but in the lower tunnel it becomes steeper. The vein follows for most of its course the contact between granite on the footwall and diorite porphyry on the hanging wall, but in places either rock may occur on both walls of the vein. The vein is contained in a shear zone, and the width of the ore ranges from a few inches to several feet. The wider parts of the vein have been stoped out above the middle tunnel. In places there is much gouge material along the vein and in the ore. The wall rocks of the vein have been largely altered, and sericite is abundant. The shear zone in the porphyry has been penetrated by a crosscut 20 feet long, a short distance from the portal of the lower tunnel. Here numerous small seams of pyrite are exposed which trend at small angles to the course of the main vein fissure.

The ore is similar to that from the Mountain Chief mine and consists of sulphides, generally in small veinlets, relatively free from quartz, and a quartzose ore with stibnite in the interstices and in vugs of the quartz crystals. Ore of this type has a high gold content.

Pyrite is the most abundant sulphide, but locally sphalerite occurs in notable quantities.

GOLD HILL.

The Consolidated Gold Hill and Iowa group (Nos. 13 and 14) at Quartzburg consists of 14 claims, 11 of which are patented. It includes the Newburg, Homeward Bound, Elizabeth, Mayflower, Confederate, Dunlap, Gold Hill, Pioneer, Lone Star, Mountain Girl, and Iowa claims. The property, of which E. E. Carter is manager, is controlled by the Boston & Idaho Gold Dredging Co. The reported production from the workings of this group exceeds \$5,000,000, but mining is now being done only through the Pioneer shaft. The Pioneer claim has produced \$200,000 in the last seven years. The veins of this group were located in the early sixties and have been productive with short interruptions since 1864. Three stamp-amalgamation mills, the Iowa, Last Chance, and Pioneer, treated the ores, but the Pioneer is the only one now operated. In the early days considerable gold was obtained from surface workings and the sluicing of disintegrated vein matter on the Newburg, Homeward Bound, Elizabeth, and Mayflower claims.

Three well-defined productive ore zones have been exploited on the Gold Hill group. The northernmost of these zones is the Iowa, which, according to Lindgren, is a narrow vein very rich in free gold that strikes in the northeasterly direction common to most of the veins in the porphyry belt and dips southeast. The wall rocks are granite.

The Gold Hill vein, a short distance south of the Iowa vein, is defined by Lindgren as a well-defined quartz vein which strikes N. 70° E. and dips 70° S. The footwall is granite, and on the hanging-wall side is a belt of porphyritic rocks several hundred feet wide. The vein is irregular and ranges from a few inches to 6 feet in width. From it rich stringers extend into the porphyry hanging wall. This vein is regarded as the continuation of the Mountain Chief and Belshazzar vein. Most of the production of the claim group has been derived from the Gold Hill vein.

The third mineral zone is a zone of shearing in the porphyritic rocks of the Pioneer claim. It contains rich narrow seams of gold ore in highly altered wall rocks.

The Pioneer claim is developed by a shaft 500 feet deep and levels at 100, 250, 400, and 500 feet below the collar. Approximately 6,500 feet of drifts and crosscuts have been driven. The 400-foot level connects with old workings on the 400-foot level of the Gold Hill shaft. The production from the Pioneer shaft dates from 1884, but work has not been carried on continuously. In 1908 the shaft was unwatered after a period of inactivity, and the property has produced for most of the time since then.

The dominant country rock of the Pioneer mine consists of quartz diorite porphyry and closely allied rocks, which are described on page 91. Apparently intruding the quartz diorite porphyry, though in places separated from it by faults, are dikes and masses of diorite porphyry that have a maximum thickness of 100 feet. Narrow dikes of lamprophyre also occur. All the rocks are highly altered, but most extensively adjacent to the veins, where the rocks are of much lighter color. Sericite is abundantly developed as an alteration product of the feldspars, and hornblende and biotite are largely altered to chlorite. Pyrite in well-developed cubes is abundant throughout these rocks.

The ore occurs as narrow veinlets or seams in shear zones which trend generally northeast. In some places these seams are abundant enough to form ore bodies 50 feet or more long and 20 to 30 feet wide; in others a single vein may be mined for a considerable distance along its strike. In general, however, the ore bodies have little regularity; the seams of which they are made up have no great persistence and in places end abruptly. The ore occurs both in the quartz diorite porphyry and the diorite porphyry, the contact between the two porphyries being a favorable site for ore development. Because the rocks in the shear zones are highly altered, the appearance of ore and barren country rock is very similar and therefore constant panning is necessary for the determination of the ore.

The ore consists of quartz carrying free gold associated with stibnite and sphalerite or of these sulphides with little quartz. The gold is coarse and in some specimens from the 400-foot level coarse flakes of it are coated by the black antimony mineral. Generally, however, the gold can not be detected until after the ore has been crushed and scoured in the pan. On the 400 and 500 foot levels narrow rich seams have been recently encountered in drifts west from the shaft, and their development may lead to the discovery of valuable ore bodies in this part of the mine, which has been little explored between the 250 and 500 foot levels.

The mine force consists of about 35 men, employed in two shifts. Square-set timbering is used in the wider stopes. Drifts are run at a cost of \$3.50 to \$5 a foot.

The mill has a capacity of 50 tons a day. The ore is roughly crushed by 20 stamps and then is further reduced in a Lane slow-speed mill to pass a 30-mesh screen. In this process the gold is polished and largely liberated from the sulphides. The overflow from the Lane mill passes over plates, where approximately 80 per cent of the gold content is saved, and it is finally treated on Wilfley tables. Concentrates of two grades are obtained. Those of the first class, which contain much stibnite, assay over \$100 a ton, and those of the second class, mostly pyrite, assay about \$15 a ton. The con-

concentrates were treated with cyanide solutions for a time, and the managers intend to resume that treatment. The average value of the ore treated during 1914 was \$5 to the ton, but at the time of visit ore of much higher grade was being mined.

CARROLL-DRISCOLL.

The Carroll-Driscoll group (No. 15) comprises 14 claims which extend in a northeasterly direction from the end lines of the Gold Hill group to Garden Valley Pass. The property was worked in the early days, and many thousand dollars' worth of gold was produced from surface workings and by sluicing disintegrated veins on the Ivanhoe and Capital claims, at the head of California Gulch. The principal development work on this group consists of two tunnels, 178 feet apart, on the Ivanhoe claim. The upper tunnel, which is several hundred feet long, is now partly caved. It is a shallow drift on the vein, which strikes N. 30° E. and dips steeply east. Considerable ore has been produced, but the amount is not definitely known. The ore consists of veinlets of massive pyrite and a little quartz which carry free gold. The country rock is granite.

The lower tunnel is driven in a course N. 60° W. for 1,450 feet. It intersects a shear zone 135 feet wide, which contains several sulphide veins in zones of more intense shearing. These veins trend from north to N. 30° E. and dip steeply east. The largest vein is near the hanging wall of the main shear zone, and its width ranges from 3 to 12 feet. The zone is further explored by a drift on its hanging wall and by short crosscuts driven to the main vein. The shear zone carries an abundant flow of water, which, with the softness of the vein matter, renders mining somewhat difficult.

The vein matter is composed largely of a soft white gouge which incloses the sulphides. The gouge is sericite, a secondary mica derived from the alteration of feldspars. Pyrite, in well-developed crystal aggregates or individuals, is the dominant sulphide in the gouge, but here and there are fragments of older vein material in which quartz, calcite, pyrite, galena, sphalerite, and tetrahedrite were recognized. These sulphides, however, have largely been ground up and incorporated in the gouge. It is evident that there have been two general periods of sulphide deposition and that extensive alteration and movement have occurred in the vein subsequent to the first period. Pyrite is the latest mineral in the sericite gouge, as proved by its well-developed crystal form. According to E. F. Blain, superintendent of the property, the vein assays from \$5 to \$15 a ton in gold and \$2 to \$3 a ton in silver. No assays were made to determine whether the pyrite of the lower tunnel contains any gold and silver, but it is thought more probable that these metals are contained in the older sulphides.

MOUNTAIN QUEEN.

The Mountain Queen mine (No. 16) lies west of Grimes Creek, at the southern edge of the porphyry belt. The property was recently acquired by the Golden Age Mining Co., but no work has been done on it for many years. On Grimes Creek are the burned ruins of an old 20-stamp mill which treated the Mountain Queen ore. The reported production of the mine is \$150,000. Two tunnels explore the Mountain Queen vein, one near the creek level and the other 200 feet higher and about 150 feet below the divide between Payette River and Grimes Creek. Both tunnels are now caved. The vein is contained in a granite porphyry having rounded quartz phenocrysts. It trends N. 40° E., and its course for 300 feet on the surface is marked by stoped-out parts of the vein.

IDAHO.

The Idaho (No. 17) is one of the claims of the Theron group, owned by the Golden Age Mining Co. It lies on the east side of Grimes Creek opposite the Mountain Queen. A tunnel 250 feet long is driven on a vein that trends N. 35° E. and dips 65° SE. The vein is probably the continuation of the Mountain Queen vein. Only at the face of the tunnel is the vein exposed. Here a band of sulphides 2 inches wide is contained in sheared and altered diorite porphyry near the contact with granite porphyry. The ore contains pyrite, galena, and sphalerite, but its tenor was not learned.

GOLDEN AGE.

The Golden Age Mining Co. controls 21 claims, of which 8 are patented and application has been made for patent for 8 others. These claims lie on both sides of Grimes Creek and extend north-eastward 1 mile from a point near Grimes Pass. The mine is near the northeast end of the group, on the south side of Grimes Creek, at an altitude of 5,000 feet. The ore body was discovered in 1896, but the production dates intermittently from April, 1909. The mine was closed in July, 1912, but work was resumed in August, 1914, and since then about 15 men have been continuously employed. The total production is reported to be approximately \$200,000, principally in gold.

The development is directed chiefly from the mill tunnel level, on which the crosscuts and drifts aggregate about 2,000 feet. A winze 100 feet deep below the tunnel level has 500 feet of drifts. An old shaft probably not more than 200 feet deep connects with the mill tunnel.

Diorite porphyry is the dominant rock of the crosscut tunnel, but near the vein there is exposed a mass of intrusive rhyolite 100 feet thick whose relation to the diorite porphyry is not clearly shown.

The diorite porphyry is cut by several shear zones and small faults that trend nearly north and dip steeply both east and west. At 100 feet from the tunnel portal a shear zone 40 feet wide, known as the Jerry Simpson vein, is intersected. This zone contains many sulphide seams which constitute a low-grade ore, but no attempt has been made to mine the deposit. Other shear zones in the tunnel section show small sulphide veins, but only one of them has been exploited. Where cut by the tunnel the productive vein is a narrow sulphide vein in sheared wall rocks. It trends north and on the tunnel level and in the lower drift dips 60° W., but in places on the stoped-out parts of the vein above the tunnel level it dips east. The ore body is 600 feet long and has been largely removed above the tunnel level, the present production being made from stopes below it. On the tunnel level two drifts extend for 200 feet on split parts of the vein. At no place is the distance between the drifts greater than 20 feet. The split parts of the vein join at each end on the tunnel level and probably also below it, as but one ore body occurs on the lower level. Above the tunnel the two parts of the vein extend for 60 feet, the eastern limb bending over toward but not joining the western part. At the north end of the ore shoot the vein is displaced with small offsets by several east-west faults. Another fault of similar direction is apparently older than the mineralization as the vein continues through it undisturbed.

The vein is essentially an aggregate of sulphides with subordinate quartz. The sulphides are pyrite, galena, sphalerite, and tetrahedrite. Stibnite is reported to occur but was not observed in the ore. Pyrite predominates over galena and sphalerite, and these sulphides in turn are in excess of tetrahedrite.

The ore is of high grade and is valuable chiefly for its gold content, but it also contains silver. The battery feed of the ore now being mined is said to assay about \$48 a ton in these metals. Much of the ore previously mined assayed from \$7 to \$20 to the ton. Assays of samples across the vein which showed notable amounts of tetrahedrite gave as much as 35 ounces of silver to the ton. The ore now mined is much more base than that which was obtained from the upper mine workings, and a much lower saving of the precious metals is effected. The reported recovery is 60 per cent of the assay value.

The ore is treated at the mine in a mill of 15 stamps, whose capacity for a product of the desired screen size is 20 tons in 24 hours. The ore is crushed to pass a 40-mesh screen. The gold that is liberated and polished by this crushing process is caught on the plates. The overflow from the plates is treated on Wilfley tables, where concentrates of two grades are made. Those of the first class assay from \$90 to \$200 a ton, and those of the second class, which are mainly pyrite, assay only \$8 to the ton. The loss of sulphides and of amalgam in the tailings is considerable.

DIANA MINES CO.

Claims and general operations.

The Diana Mines Co. controls by ownership or lease 87 mining claims contained in 14 groups. These are the Diana, Enterprise, Golden Fleece, Ader, Doyle, Pool, Jeannot, Overlook, Butts, Isabella, Coon Dog, Whaley, Mohawk, and Independence groups. With the exception of the Golden Fleece group, near Centerville, all are on the porphyry belt in the vicinity of Grimes Pass. Only two of these groups, the Enterprise and Golden Fleece, are patented. The claims near Grimes Pass border the Golden Age group on three sides, with the open end to the east. North of the Golden Age the claims for a distance of 2 miles occupy the low divide between Grimes Creek and Payette River, and to the south they include much of the drainage basin of Charlotte Gulch. The town site of Diana lies within the boundaries of these claims at the junction of Charlotte Gulch and Grimes Creek. The company began operations late in September, 1915, and probably an average of 75 men have been employed throughout the winter. This work included the opening of old workings and extension of development, erection of mine buildings, mill operation and experimentation, mine surveying, road making, lumbering, and numerous other activities. The development work was confined to the Enterprise, Overlook, Mohawk, and Coon Dog groups. The work was somewhat hindered by an exceptionally heavy snowfall, but even under the adverse conditions substantial progress has been made. During the course of this work several carloads of ore and concentrates have been shipped. This work was begun after the writer's visit, so that several of the prospects which were not accessible at that time have since been opened. The development is not extensive on any of the groups, and consequently there is much to be learned regarding the character and extent of the ore bodies. The deepest workings accessible at the time of examination were those on the Coon Dog No. 1 claim, where a depth of 100 feet below the outcrop was attained. The lowest tunnel of the old workings on the Blackbird claim of the Enterprise group is reported to intersect the vein 650 feet below the outcrop.

The principal operations of the company are described below. On several other groups near Grimes Pass, acquired by this company, considerable work was done years ago. Excellent assay values were reported from some of the veins, but at that time the ores could not be treated or shipped profitably and the workings were allowed to cave. The company has postponed the reopening of these workings until the disappearance of the deep snow.

Enterprise.

The Enterprise group (No. 19) of five patented claims is at the head of Charlotte Gulch. These claims were known as the Ingle group and were worked about 1902, when a mill was built on the property to treat the ores. At that time the Blackbird claim was developed by three tunnels, which were driven 800, 1,100, and 1,200 feet on the vein and the lowest one of which attained a depth of 650 feet below the outcrop. The tunnels were connected by raises and a shaft was sunk to the upper tunnel. The Baby claim was developed by a shaft 150 feet deep. In 1902 the mill, it is said, treated 3,600 tons of ore, the average value of which was \$9 in gold and silver to the ton. Part of the gold was caught on the plates, and the overflow was treated on Standard tables. The average value of the concentrates was \$40 to \$50 a ton. The concentration process employed is said to have been poorly adapted to the character of the ore, and after a short run the mill was closed and development work discontinued until the property was acquired by the Diana Mines Co. This company reopened the old workings, adjusted the tables and machinery of the mill, and installed motors, the power for which was purchased from the Boston & Idaho Gold Dredging Co. In adjusting the tables 200 tons of ore was treated, from which \$1,076 in gold was recovered on the plates. About 37 tons of concentrates, including some old stock on hand, were shipped and yielded a net return of \$961.

In a recent communication Mr. F. T. Day, manager of the Diana Mines Co., gave further details of the mill treatment and smelter returns of the concentrates. The ore now being mined and treated at the mill contains approximately 0.25 ounce of gold and 4 ounces of silver to the ton and 2 per cent of lead. The ratio of ore to the concentrated product is about 8 to 1, and the saving effected by the mill treatment is 85 per cent of the assay value of the ore. This ore was not amalgamated. The average metal content of two shipments of concentrates was 1.56 ounces of gold and 12.6 ounces of silver to the ton, 0.7 per cent of copper, 12.9 per cent of lead, and 8.3 per cent of zinc, aggregating in value about \$57 to the ton at the current price of metals at that time. During a three weeks run in March, 1916, the mill produced 32.48 tons of concentrates whose average assay value was \$65.7 to the ton. The net smelter return on 130.845 tons of concentrates was \$4,285.

The vein trends N. 70° E. and dips 65° S. Where exposed by sluicing at the caved portal of the lowest tunnel it is contained in an iron and copper stained shear zone about 20 feet wide. The ore body is said to be from 4 to 12 feet wide. The country rocks, which are poorly exposed, are granite and granite porphyry. In places the sheared and altered granitic hanging wall of the vein contains disseminated crystals of pyrite, galena, and sphalerite, which may ex-

tend 20 feet from the main fissure. The ore as noted on the dump of the lowest tunnel is composed of pyrite, sphalerite, galena, and a little chalcopyrite. The gangue is a fine-grained quartz that in part appears to have been introduced in the fissure after the deposition of the sulphides. The ore in the upper workings is partly oxidized, and some of the galena is altered to cerusite. In this part of the ore body the lead minerals were apparently in excess of the zinc minerals.

Mohawk.

The two claims of the Mohawk group (No. 20) adjoin the Enterprise group on the north. The Mohawk vein was discovered in 1914, and the development work on it consists only of a short discovery tunnel, a crosscut tunnel 100 feet lower, near the bottom of the gulch, a raise connecting the two tunnels, and short drifts on intermediate levels. In all there is about 300 feet of development work.

The vein occurs in a shear zone in granite and granite porphyry. It strikes N. 70° E., dips 60° S., and is approximately parallel to the vein on the Enterprise claim. The vein is explored by drifts for a distance of 75 feet only, and therefore little is known regarding its continuity. On the outcrop the vein consists of iron-stained honey-combed quartz which contains some unaltered pyrite and galena, but on the 50 and 100 foot levels the sulphides are unaltered.

In places the ore is several feet wide. In the west drift from the lower tunnel the ore shoot pinches out in the fissure, but in a recent extension of this drift ore was again struck. Free gold occurs in the ore, and it is reported that 100 tons obtained near the surface was treated in a 2-stamp mill on Grimes Creek and yielded \$22 to the ton on the plates. Pyrite, sphalerite, galena, chalcopyrite, and a little tetrahedrite constitute the sulphides. A polished section of ore shows large crystals of sphalerite and smaller ones of pyrite and a few of tetrahedrite in granular quartz. The sphalerite is thoroughly shattered; the fragments are more or less detached, and the interstices are filled with quartz. This indicates that the sphalerite was first deposited and later shattered by movements along the fissure and the quartz was then deposited in and about it. Chalcopyrite and galena are closely contemporaneous with the sphalerite, but some of the tetrahedrite and pyrite are associated with the later quartz.

Coon Dog.

The Coon Dog group of 10 unpatented claims extends in an east-west direction along the divide between Grimes Creek and Payette River and in part across Grimes Creek. Assessment and development work was done on these claims by J. H. Ballinger from 1903 until they were acquired by the Diana Mines Co. Since January 1, 1916, this company has shipped several carloads of copper ore, and

development is actively in progress. The net payment by the United States Smelting Co., of Salt Lake City, Utah, on 95.61 tons of ore was \$1,588.85, or about \$16.62 to the ton. The freight, sampling, and smelting charges are about \$12 to the ton.

At the time of visit the principal development work was on Coon Dog No. 1 and Coon Dog No. 4 claims. The tunnel portal of Coon Dog No. 1 claim (No. 21) is on the south side of Grimes Creek, 100 feet above the stream. At the time of examination the tunnel was 330 feet long and attained a depth of 100 feet below the surface. This tunnel has since been extended 160 feet. Several veins were intersected by the Ballinger development, and two or more have since been cut. The veins trend N. 70° E. and dip at an average of 50° S. Veins with similar trend were noted in the creek bed several hundred feet from the tunnel, and in the Coon Dog No. 4 claim, which lies on the Payette slope probably half a mile distant. A number of parallel veins are exposed at points several thousand feet apart, but it is not known that any one vein is continuous throughout this distance. In the tunnel on No. 1 claim the first vein is encountered 84 feet from the portal. The vein, which is largely oxidized but contains some pyrite, is a shear zone about 4 feet wide in rhyolite. It is developed by drifts 60 feet each way from the tunnel. According to Mr. Ballinger, samples across the vein assayed from \$6 to \$100 to the ton in gold. At 280 feet from the portal is another vein 3 feet wide, but it is undeveloped. It contains pyrite, sphalerite, and chalcopyrite, and an assay of it is said to have given returns of \$2.70 in gold and 11 ounces of silver to the ton and 12 per cent of copper. Near the face of the tunnel the rhyolite is greatly sheared and contains a somewhat distorted vein, which is developed for a short distance east of the crosscut tunnel. This vein shows in places 2 feet of high-grade ore.

This vein was further developed in the east drift by the Diana Mines Co., and it is the source of the ore shipments. Assays of two carload lots of ore as determined by the United States Smelting Co. are as follows:

Assays of ore from Coon Dog group.

Gold.	Silver.	Copper.	Lead.	Iron.	Insoluble.	Zinc.	Sulphur.
<i>Ounces per ton.</i>	<i>Ounces per ton.</i>	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>
0.1525	13.43	4.95	0.85	15.25	48.65	7.05	18.9
.105	14.55	5.56		15.9	44.4	7.2	19.88

From these data it is apparent that the ore is valuable chiefly for its copper and silver content, although it carries between \$2 and \$3 in gold to the ton. The country rock of the tunnel is chiefly rhyolite, but in several of the shear zones altered dark-colored dike rocks

were noted. The sulphide ore consists of pyrite, sphalerite, and chalcopyrite. The sphalerite and chalcopyrite are in close association, and the chalcopyrite is here and there partly replaced by covellite or chalcocite. Native copper was noted in fine seams in shattered rhyolite obtained near the surface, but the zone of oxidation is shallow.

The tunnel on the Coon Dog No. 4 claim (No. 22) lies on the steep slope to Payette River about 450 feet below the divide between the Payette and Grimes Creek. The openings, including a drift of 100 feet, amount to about 250 feet. The vein strikes N. 70° E. and dips 60° S. The ground is heavy and requires timbering. At the face of the drift the vein is 26 inches wide, and is inclosed in sheared and altered granite porphyry. In other parts of the drift the mineralized fissure, it is reported, is 10 feet wide. The ore is of heavy sulphide character, and consists of pyrite, chalcopyrite, sphalerite, and a little tetrahedrite in a gangue of quartz and altered porphyry. It is reported to carry a considerable silver content, but no assays of it were available.

The veins of the Coon Dog group may be developed to considerable depths by long tunnels driven on the Payette River slope on the Coon Dog No. 4 claim, below the present tunnel, and on the Independence claim, which adjoins on the east the Coon Dog No. 4 claim.

OTHER MINES AND PROSPECTS.

Many other prospects along the Quartzburg and Grimes Pass porphyry belt are not mentioned in this report. Some will probably prove of economic importance, but their present lack of development gives little opportunity for the study of the ore deposits.



DEPARTMENT OF THE INTERIOR

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THE GOLDEN ARROW, CLIFFORD, AND ELLENDALE
DISTRICTS, NYE COUNTY, NEVADA

BY

HENRY G. FERGUSON

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THE GOLDEN ARROW, CLIFFORD, AND ELLENDALE DISTRICTS, NYE COUNTY, NEVADA.

By HENRY G. FERGUSON.

INTRODUCTION.

In connection with other work in central Nevada an opportunity arose for brief visits to the three small mining camps here described. Such observations as could be made in the short time available are presented as a minor contribution to information concerning the ore deposits of Nevada.

Golden Arrow and Clifford are situated at the western base of the Kawich Range in Nye County, Nev., and are reached by automobile from Tonopah. The Clifford district is on the main road between Tonopah and Ely, about 35 miles east of Tonopah, and Golden Arrow is 12 miles southwest of Clifford. Neither district has yet produced much ore. At the time of visit one man was working at Clifford and three at Golden Arrow. Ellendale, a few miles east of Tonopah and a short distance south of the Tonopah and Ely road, is now abandoned. The opportunity of visiting these districts was due to the kindness of Capt. W. G. Cotter and Mr. D. Johnson, of Goldfield.

The Kawich Range and its northern continuation, the Hot Creek Range, were visited by Spurr during his reconnaissance of southern Nevada in 1899, and the following description of the Kawich Range¹ is quoted from his report:

The Kawich Range forms the southern continuation of the Hot Creek Range, from which it is separated at its northern end by a narrow transverse pass. From this point it extends due south about 60 miles, where its southern end runs out into the desert valley. The range is high and is deeply eroded into bold, craggy mountains. On both sides the slope of the mountains is steep, especially on the west, where there are almost impassable cliffs. On the flanks of the range on both sides of the rugged backbone are smooth mesa-like forms.

In 1905 Ball² made a more detailed study of the part of the range south of the thirtieth parallel. The accompanying map (fig. 13) is taken from the geologic map in his report. In the southern part

¹ Spurr, J. E., Descriptive geology of Nevada south of the fortieth parallel: U. S. Geol. Survey Bull. 208, p. 181, 1903.

² Ball, S. H., A geologic reconnaissance in southwestern Nevada and eastern California: U. S. Geol. Survey Bull. 308, pp. 99-114, 1907.

of the range are areas of Paleozoic sedimentary rocks which are correlated with the Pogonip limestone and Eureka quartzite of the Eureka section. The section (fig. 14) given in Ball's report¹ shows eastward-dipping monoclinical structure.

A considerable thickness of Silurian sediments is exposed on the eastern flank of the Hot Creek Range,² and rhyolite forms the western side of the range. The sedimentary series is cut by two normal faults striking north, with downthrows to the east of 1,000 and 300 feet. Spurr considers that these faults are pre-Tertiary, and his map indicates that they do not continue into the area covered by Tertiary volcanic rocks.

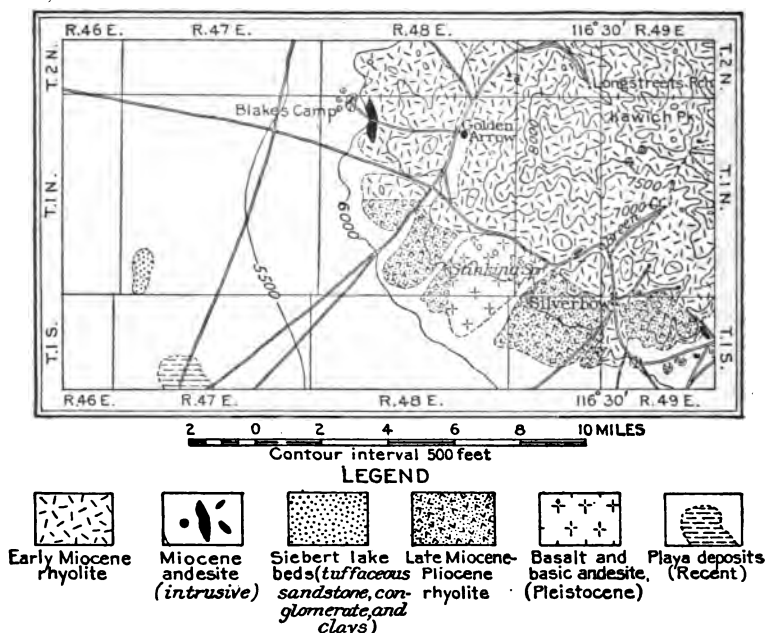


FIGURE 13.—Geologic map of Golden Arrow, Nev., and vicinity. The area without pattern is occupied by Quaternary gravels and sand. (After S. H. Ball.)

The Reville Range, the next range of the Kawich, has westward-dipping Cambrian strata on its east side,³ and Ball⁴ states that the eastern slope of the range is the more precipitous.

West of the Kawich Range, midway between it and Tonopah, are the Stone Cabin Hills, the southern extension of the Monitor Range. These are a group of low irregular hills which, so far as could be observed, consist of rhyolite and tuff with small masses of intrusive andesite. Gilbert⁵ has noted a spur of metamorphic rock

¹ Ball, S. H., op. cit., p. 108.

² Spurr, J. E., op. cit., pp. 85-87.

³ Idem, p. 152.

⁴ Ball, S. H., op. cit., p. 113.

⁵ Gilbert, G. K., U. S. Geog. and Geol. Surveys W. 100th Mer. Rept., vol. 3, p. 121, 1875.

on the west side of the range at its south end. Ball's map shows Paleozoic sediments and later granitic intrusives on the west side of the Cactus Range, which lies to the south of the Stone Cabin Hills. The northern part of the Monitor Range, according to Spurr,¹ shows a scarp facing westward.

Neither Spurr² nor Ball³ considers that faulting played any important part in the origin of the Basin Ranges, but recent studies by Davis⁴ and Louderback⁵ have shown that certain of the ranges are undoubtedly due to faulting. As regards many of the ranges, including the Kawich, the evidence is not conclusive in favor of either hypothesis. If the ranges represent tilted fault blocks, erosion has proceeded far enough to remove direct physiographic evidences of faulting. The steeper western front of the Kawich Range, the wall of cliffs on its west side, and its eastward-dipping monoclinical structure constitute evidence favoring the conclusion that the range is a fault block tilted to the east. The monoclinical structure shown in the section is, however, explained by Ball⁶ as the western limb of the

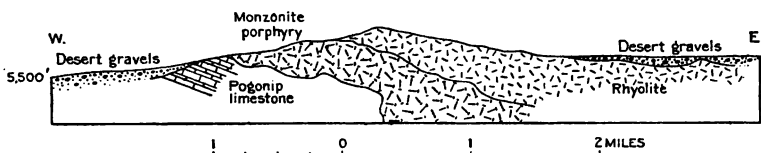


FIGURE 14.—Section across Kawich Range $2\frac{1}{2}$ miles north of Kawich, Nev. (After S. H. Ball.)

Reveille Valley syncline. Evidence against faulting is found in the presence of many small hills, such as Deadhorse Hill, at Golden Arrow, and the andesite hill at Clifford, which form outliers to the east of the range, and the fact that the desert wash does not reach the mountains but is separated by a belt of rock-surfaced plain. These features are not incompatible with faulting, however, if the time since the formation of the range has been sufficient to allow eastward retreat of the fault scarp for a few miles, with consequent loss of regularity.

GOLDEN ARROW DISTRICT.

The Golden Arrow district lies a few miles south of the north end of the Kawich Range and nearly 40 miles east of Tonopah. Although the low Stone Cabin Hills lie between, the lights of the

¹ Spurr, J. E., op. cit., p. 89.

² Spurr, J. E., Origin and structure of the Basin Ranges: Geol. Soc. America Bull., vol. 12, pp. 217-270, 1901.

³ Ball, S. H., op. cit., p. 42.

⁴ Davis, W. M., The mountain ranges of the Great Basin: Harvard Coll. Mus. Comp. Zool. Bull. 42, Geol. ser., No. 6, 1906.

⁵ Louderback, G. D., Basin Range structure of the Humboldt region: Geol. Soc. America Bull., vol. 15, pp. 219-346, 1904; vol. 18, pp. 663-669, 1906.

⁶ Ball, S. H., op. cit., p. 42.

Tonopah-Belmont mill are clearly visible from Golden Arrow. The mines are situated on a narrow strip of rock-cut plain between the mountains and the desert valley to the west. There is no sharp line between desert wash and rock outcrop, and the loose material near the mountains is clearly only a thin veneer on the underlying rock. The region is barren and desolate, supporting only scanty desert vegetation, but the higher hills to the east carry a sparse

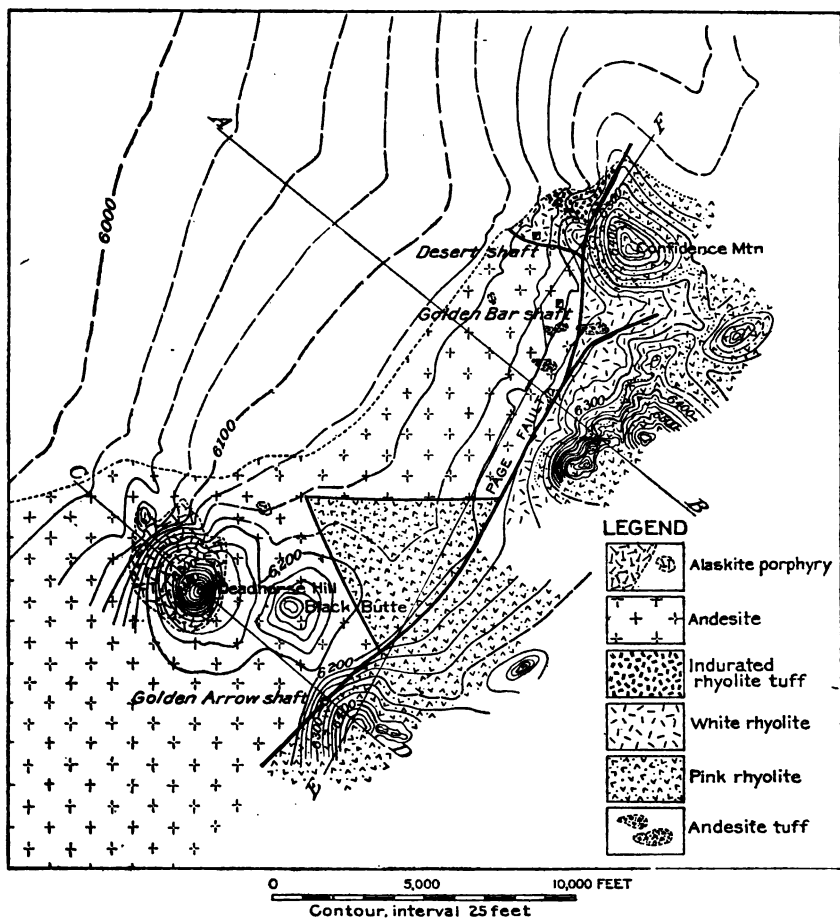


FIGURE 15.—Map showing geologic relations in vicinity of mines at Golden Arrow, Nev.
By J. D. Irving.

growth of pine and juniper. Water for domestic purposes is hauled from a spring on the Longstreet ranch, about 7 miles to the northeast.

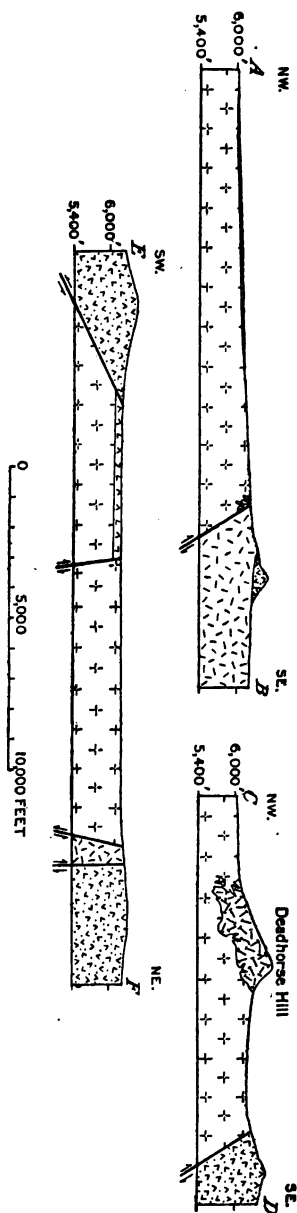
The geology of the district has been studied in detail by Prof. J. D. Irving in the course of an examination of the property of the Cotter Mines Co., and the accompanying map and sections (figs. 15 and 16) are reproduced by his permission. The rocks ex-

posed are alaskite porphyry (or tordrillite), andesite, rhyolite tuff, and rhyolite.

Deadhorse Hill consists of a mass of light-colored porphyritic rock, shown on Irving's map as granite porphyry (alaskite), presumably the rock called tordrillite by Spurr. The rock is white and almost granitic in appearance, the phenocrysts exceeding the groundmass in volume. The feldspar individuals are large, some of them 6 millimeters in length, and are far more numerous than those of quartz. Both orthoclase and oligoclase are present, the former in greater abundance. The quartz phenocrysts are rounded and show deep magmatic embayments. Other original minerals are very sparingly present and consist of small shreds of muscovite and biotite, the latter now almost completely chloritized. The groundmass is an extremely fine-grained mixture of quartz and feldspar. Although there is nothing in the texture or occurrence of the rock to preclude its being a well-crystallized portion of a rhyolitic flow (tordrillite), it seems more probable, both from its texture and from its mineral composition, that it is allied to the earlier granitic intrusions, or represents a phase of the intrusive activity of early Tertiary time, which produced masses of various porphyries, chiefly silicic types, in several parts of southern Nevada.¹ If this is the case, the mass crowning Deadhorse Hill and the small areas in the flat to the north must be considered as remnants of the original roof of the andesite intrusion or less probably, in view of the size of the Deadhorse mass, included blocks in the andesite.

Rhyolite forms the mountain range immediately east of the district. Irving has mapped a white rhyolite and a later pink rhyolite,

FIGURE 10.—Geologic sections on lines indicated in figure 15. By J. D. Irving.



¹ Ball, S. H., op. cit., p. 32.

but there seems to be little other than color to distinguish the two. The rhyolite contains abundant quartz phenocrysts, feldspar in smaller amounts, and a little biotite in prominent small crystals. The feldspar are albite and orthoclase.

On a low ridge north of the Cotter property there is an outcrop of thin-bedded tuffaceous sandstone, which consists principally of quartz with a few grains of feldspar. In the single slide examined orthoclase was the only feldspar observed. The matrix appears to be composed chiefly of minute quartz grains. Small specks of dark slate and minute fragments of slightly sericitized rhyolite are to be seen in the coarse-grained layers, but no trace of andesitic material was found. Ball noted similar rocks in other parts of the Kawich Range and correlated them with the Siebert tuff.

The rock plain between the rhyolite hills on the east and the desert valley on the west and north is for the most part composed of andesite. The andesite is a rather fine-grained porphyritic rock, with numerous small feldspar phenocrysts, mostly under 3 millimeters in length. Microscopic determination of the feldspars indicates andesite (An_2Ab_1). The feldspars are largely replaced by calcite, but no sericite has been developed. Indefinite dark specks represent original ferromagnesian minerals. Under the microscope it is seen that the ferromagnesian minerals are entirely altered to a mixture of chlorite, calcite, a little quartz, and, rarely, zoisite. From the shape of these pseudomorphs it appears that hornblende was originally the most prominent of the dark silicates, though augite may also have been present. No flow structure is recognizable, though irregular areas of chlorite suggest the filling of amygdaloids.

The andesite appears to be intrusive into the alaskite porphyry of Deadhorse Hill, though the writer was not able to confirm his impression by the study of actual contacts. The irregular contact of andesite and rhyolite exposed in the workings of the Desert shaft likewise suggests intrusion, but there the relations of the two rocks are masked by the extensive slipping which has taken place. On the other hand, specimens collected on the dump of the Gold Bar shaft and said to come from the 400-foot level show a decidedly andesitic tuff in close association with the andesite, and outcrops of a similar tuff are shown on the map (fig. 15).

Faulting has affected all the rocks exposed in the district. The principal fault, called the Page fault on Irving's map, follows the line of the hills in a general northeasterly direction and dips to the southeast at an average angle of about 60° . It is probably a normal fault, and the downthrow is therefore to the east. It forms the boundary between the andesite and rhyolite over the greater part of its known length. Between the Golden Arrow and Cotter mines,

however, east of the fault, there is a triangular area of rhyolite that is itself bounded by faults. This seems to represent a sunken block on the upthrow side of the main fault, bounded by minor faults contemporaneous with the larger one. A similar subsidiary fault separates the rhyolite and andesite on the Desert and Gold Bar claims of the Cotter property. The throw of the faults is unknown but is probably not more than a few hundred feet.

The mineralization is believed to have followed the faulting closely and to belong to the same general period. The Page fault appears to be mineralized at the Golden Arrow mine and in the prospects to the southwest, although so far as can be judged from specimens collected on the dump, the main ore body was within the rhyolite. Most of the veins in the Cotter prospects appear to branch out from the fault nearly at right angles and have not been found to continue for any great distance from it. The arrangement of the vein system here suggests that the fissures now filled by vein matter are subsidiary to the main fault. North of the Desert fault the ore is in the rhyolite, and here the fracturing is less distinct than in the andesite area. East of the Page fault ore is likewise found in the rhyolite but in less well-defined veins than where the andesite forms the country rock.

Some faulting probably took place after the deposition of the ore, for the vein at the Desert shaft appears to be cut off by a later fault parallel to the Desert fault, but the work done is insufficient to determine this point with any certainty.

Although considerable work has been done on the two principal groups of the district, there has been almost no production. In October, 1915, a little work was going on at the Cotter property, and two prospectors were at work on some claims to the west.

The shaft at the Golden Arrow mine appears to follow the Page fault, which here strikes about northeast and dips 60° SE., and both andesite and rhyolite are found on the dump. The ore, however, seems to lie entirely within the rhyolite and to consist of small quartz-filled fissures carrying a few specks of sulphides. The wall rock close to these fissures is silicified, but does not appear to be sericitized.

Pyrite is the principal metallic mineral present, but here and there throughout the quartz are very minute specks of a dark cleavable mineral, probably zinc blende. The quartz is glassy, and in most specimens distinctly vuggy. Slender crystals as much as an inch in length project outward from the walls or radially from included fragments of silicified rhyolite or from pyrite. In the vugs small quartz crystals of a second generation line the faces of the larger crystals. More rarely quartz is seen in small plates studded with minute crystals. In this position it appears to replace lamellar

calcite. Silver is said to be the principal valuable constituent of the ore, gold being present only in very small quantity. A 10-stamp mill has been set up but was never used, and the production of the mine is unknown.

The principal working of the Cotter Mines Co. is on the Gold Bar claim, where a vein has been developed by an inclined shaft 500 feet in length. Only the upper 140 feet, however, was accessible at the time of the writer's visit. The vein has a northwesterly course and a southwesterly dip. The angle of dip varies in different parts of the shaft between 43° and 60° . At points where the vein could be seen it consists of a series of closely spaced parallel quartz veinlets with pyrite. In places a small quantity of very light colored gold, said to have approximately the composition of electrum, is present in the ore but is so finely divided as to be visible only in the pan. Two ore shoots have been developed, one on the northwest and the other on the southeast side of the shaft. The northwestern shoot has been lost on the 400-foot level, but the other continues as far as development work has progressed. The ore averages about \$25 a ton, chiefly in gold, but ore with an average tenor of \$100 a ton can be obtained by sorting. The fineness of the gold appears to be highest close to the surface, the proportion of silver increasing with depth. Pyrite is the only other metallic mineral found associated with the best ore. Outside of the ore shoots marcasite is present as well as pyrite.

The Desert shaft is in rhyolite a few feet north of the Desert fault. The best ore occurs in an irregular crushed zone approximately parallel to the fault and about 20 feet to the north. In contrast to the better-defined veins within the andesite area, the ore here is spotty and irregular and occurs in poorly defined zones of crushed rock within the rhyolite. The ore shoot that is followed down from the surface in the shaft appears to be cut off by a later fault, though the evidence is not entirely clear. This is the only case of post-mineral faulting found in the district. The deepest level, 130 feet on the incline, has been most fully developed and shows a fairly definite though narrow eastward-trending mineralized zone, paralleling the Desert fault and from 10 to 25 feet to the north. Exploratory work farther north has shown a band of andesite about 50 feet wide whose northern and southern contacts strike on the average N. 75° E. and N. 70° E. and dip 45° N. and 70° S., respectively. The level above, 88 feet on the incline, shows only rhyolite. Intense crushing on the contacts has obscured the relations of the two rocks. The andesite is beneath the rhyolite and may be intrusive, but it is possibly the older of the two and represents an irregular surface on which the rhyolite was laid down.

There are several prospects in the rhyolite east of the Page fault, but only one was being worked at the time of the writer's visit. The Hot Tamale claim adjoins the Cotter group on the east, and the workings lie about 100 feet to the east of the fault. The mineralization appears in fissured zones in the rhyolite that carry minute seams of iron-stained quartz. The crushed ore when panned shows extremely minute colors of gold.

CLIFFORD DISTRICT.

The Clifford district is about 12 miles northeast of Golden Arrow, on the western flank of the Kawich Range, near the pass that separates the Kawich and Hot Creek ranges. About midway between Clifford and Golden Arrow is the deserted district of Bellehelen, which was not visited. The main road between Tonopah and Ely passes close to the mine workings, which occupy a low hill that juts out into the desert valley. The region, like the Golden Arrow district, is barren and desolate, as it is below the zone of tree growth.

The greater part of the small hill is composed of thin-bedded rhyolitic sandstone and pyroclastic rocks, rhyolitic tuff, and breccia. Andesite similar to that of Golden Arrow occupies the extreme western point of the hill. Although no clear contact was seen, it seems most probable that the andesite is not intrusive into the pyroclastic rocks, for in some of the specimens collected there are pebbles of a much altered andesitic lava inclosed in a matrix of fine-grained quartz fragments.

Most of the work in the district has been done by James Clifford in the oxidized ores near the surface. The hill is covered with small shafts and irregular inclines where rich streaks have been followed for short distances. Few, however, have been found profitable for more than a few feet below the surface. A 200-foot shaft on the western point of the hill reached the sulphide zone but disclosed no definite ore bodies, and the writer was informed that this shaft had been abandoned by the lessee who sank it.

The ore of the shallow workings consists of heavily iron-stained tuff cut by small quartz veins that contain small irregular masses of limonite. Close examination of the richer ore reveals cerargyrite, mostly stained brown by iron oxide but in part light green, and a few minute threads of native silver. In the specimens examined microscopically the cerargyrite grains occur in minute veinlets of light-brown jarosite. Rare specks of a silver sulphide mineral and pyrite, the latter surrounded and partly replaced by jarosite, were seen in the oxidized ore. A small amount of free gold of a light-yellow color is present in concentrates obtained by panning the richer ore.

The sulphide ore was seen in place on the 200-foot level of the shaft at the western point of the hill. The shaft itself is sunk entirely in andesite, but the drift enters rhyolitic agglomerate a few feet east of the shaft. Along the line of junction both rocks are much sheared and heavily pyritized. The contact is approximately vertical, and this fact, together with the presence of andesitic material in the agglomerate, makes it probable that the andesite is here older than the agglomerate and faulted against it. From the smallness and irregularity of the stopes it may be inferred that the ore is spotty in its occurrence. Most of the stopes are less than 6 feet in width by 20 feet in length. Although the andesite is pyritized near the contact, the ore appears to be entirely within the agglomerate. The greater part of the material shows heavily pyritized agglomerate, in places almost completely converted into pyrite, the matrix and pebbles being equally affected. The richer ore consists of agglomerate with less pyrite but cut by small drusy quartz veins. The vugs of these veins contain small crystals of stephanite, pyrrhite, and proustite, as well as pyrite and more rarely marcasite, resting on the projecting quartz crystals, and the silver sulphide minerals also occur in minute streaks between quartz and wall rock. No gold or native silver was found in the concentrates. The presence of marcasite is taken to indicate that this ore does not represent the original ore as deposited but is to a large extent, at least, the product of enrichment by downward-migrating surface waters.

ELLENDALE DISTRICT.

The deserted district of Ellendale lies on the road between Tonopah and Stone Cabin, a few miles east of Tonopah. The claims were located a few years ago, and the rich surface showings started a rush which was a miniature repetition of those following the discovery of such camps as Tonopah, Goldfield, and Manhattan. A town was laid out and houses were built, but to-day a single empty house marks the site of the town. The extent of the older workings is considerable, but apparently only a very small amount of ore was of sufficiently high grade to be shipped. In 1910 there was shipped from the district 26 tons of ore containing \$18,349 in gold and 718 ounces of silver, valued in all at \$18,737, or \$720.65 a ton.¹ In 1911, 94 tons was shipped, carrying \$54,702 in gold and 1,823 ounces of silver, with a total value of \$55,668, or \$592.21 a ton.²

Most of the workings are in rhyolite, near the contact of andesite porphyry. The rhyolite is fine grained and rather siliceous and carries small phenocrysts of quartz and feldspar. Biotite in rare and

¹ U. S. Geol. Survey Mineral Resources, 1910, pt. 1, p. 525, 1911.

² Idem, 1911, pt. 1, p. 689, 1912.

minute plates is the only ferromagnesian mineral present. The andesite is similar to that of Clifford and Golden Arrow, but the relations of the two rocks could not be determined.

So far as a very hasty inspection showed, no mining of any importance had been undertaken in the andesite area.

The mineralization consists in the irregular veining of the rhyolite by numerous little fissures filled with iron-stained quartz and the silicification and to a less degree the sericitization of the adjacent rock. The rhyolite in the mineralized zone also shows numerous brown specks, resulting from the alteration of pyrite. Microscopic examination of the ore shows that these rusty specks are composed in part of jarosite. The silicified rhyolite is also cut by minute veinlets of jarosite, few of which exceed 0.1 millimeter in width. It appears that the oxidation of the pyrite in conjunction with the weathering of a potassic rock has resulted in the formation of the sulphate jarosite instead of merely the hydrous oxide limonite.

CONCLUSIONS.

The three districts here described, although varying in the nature of their ore, show certain features in common. The deposits belong to the class of shallow vein deposits in which the mineralization followed closely the extrusion of lavas, or the welling up of intrusives that reached close to the surface. In each case the occurrence of the ores in close association with andesite is significant. It may be that one of the principal periods of Tertiary mineralization is to be associated with an epoch of andesitic volcanism. In the Manhattan and Tonopah districts there are masses of similar andesite, intrusive at Manhattan and occurring both as flows and intrusions at Tonopah, but in the Manhattan district the relations of the andesite and ore are not clear, and at Tonopah, according to Spurr,¹ the ores of the different periods of vein formation are associated with rhyolite rather than with andesite.

At Clifford and Ellendale jarosite, a sulphate of iron and potassium, takes the place of part of the limonite as a result of the oxidation of pyrite. It is believed that the potash necessary to form this mineral has been obtained from the rhyolite.

¹ Spurr, J. E., *Geology and ore deposition at Tonopah, Nev.*: Econ. Geology, vol. 10, p. 764, 1916.



DEPARTMENT OF THE INTERIOR

FRANKLIN K. LANE, Secretary

UNITED STATES GEOLOGICAL SURVEY

GEORGE OTIS SMITH, Director

Bulletin 640—G

TIN ORE IN NORTHERN LANDER COUNTY, NEVADA

BY

ADOLPH KNOPF

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TIN ORE IN NORTHERN LANDER COUNTY, NEVADA.

By ADOLPH KNOFF.

LOCATION AND DISCOVERY.

Tin ore has recently been found in northern Lander County, Nev., in an unnamed short range of hills lying 20 miles north of Battle Mountain, a town on the Southern Pacific system. The discovery was made by employees of the cattle ranch in which the range is situated. Near the base of the range is the old Izenhood ranch, which had been established at a large spring, known as Warm Spring, whose waters are used for irrigation. This ranch is now a part of the extensive cattle ranch held by Mr. George Russell, sr., of Elko, Nev.

The range in which the tin occurs trends northeastward. It rises steeply from a broad, flat valley and attains an extreme elevation of 6,000 feet, which is about 1,500 feet higher than the valley. A few miles northeast of Warm Springs the range is separated by a low, broad pass from the northern extension of the Shoshone Mesa, as it is called on the map of the Fortieth Parallel Survey, though this name appears not to be locally known. Some float wood tin has been found at the north end of Shoshone Mesa. As seen from Battle Mountain, Shoshone Mesa is a prominent feature consisting of a high, broad table-land and capped by a great thickness of black basalt, but to the north the basalt capping is absent and the mesa becomes a sharp crested ridge. The topography of the region is roughly shown in figure 17, which is reproduced, with some changes and additions, from a part of Plate IV of the atlas of the Fortieth Parallel Survey. The region is readily accessible by level roads.

Tin ore in the form of a nugget of wood tin was found on the wash at the base of the range in April, 1914, by an employee of the Russell cattle ranch. What the substance was, however, remained unknown until the fall of that year, when it was taken to Battle Mountain, where an engineer, Mr. M. G. Thurston, who had prospected a tin-bearing vein in Mexico, chanced to see it and recognized it as wood tin. The specimen was then sent to the University of California for further examination, and late in the year the report came back that the mineral was high-grade tin ore. The subsequent discovery of wood tin in its bedrock source at a number of localities

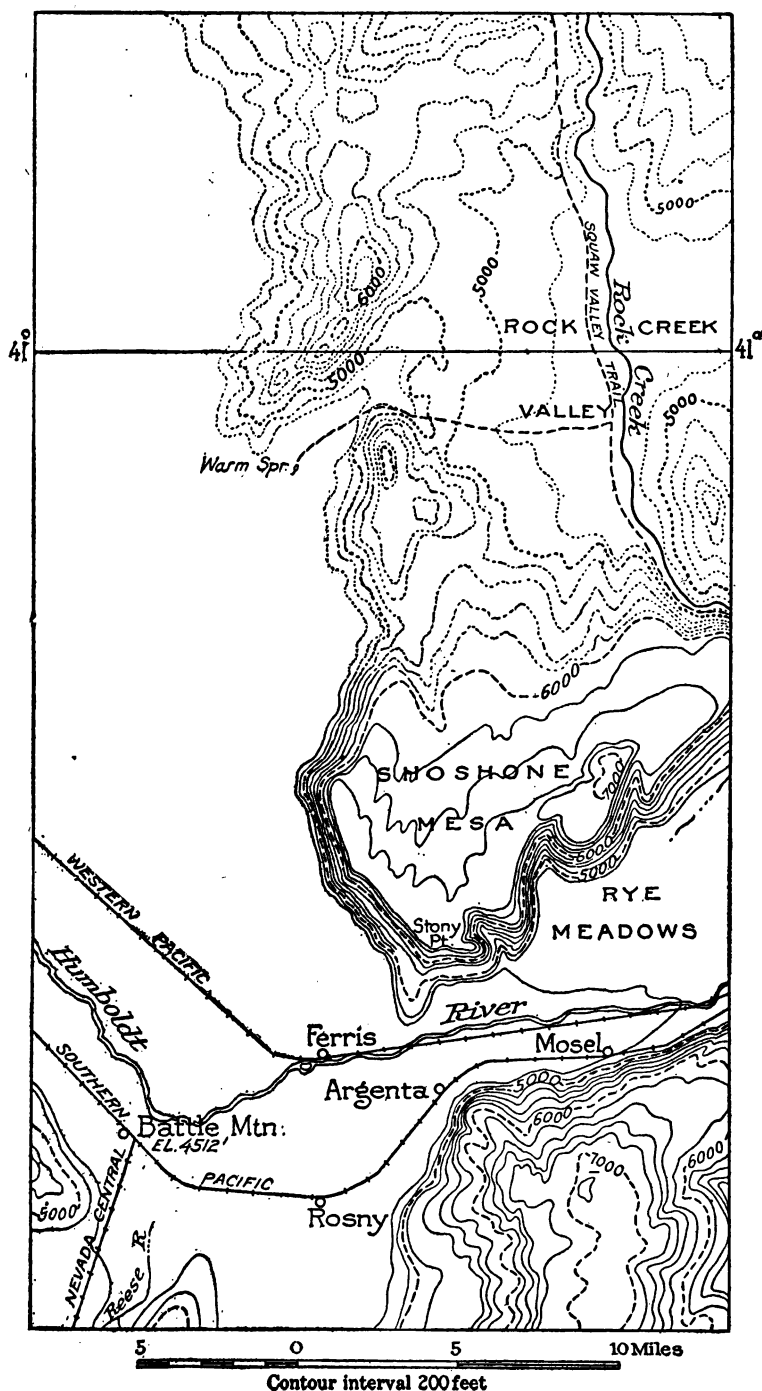


FIGURE 17.—Map of the tin-bearing area in northern Lander County, Nev., and vicinity.

was made by Edward Larson, who has also done most of the development work so far undertaken.

The prospects were examined by me early in June, 1916, and it gives me much pleasure to acknowledge my indebtedness to Mr. George Russell, sr., and Mr. George Russell, jr., for their hospitality, and to Mr. Edward Larson, whose intimate familiarity with the region greatly aided this examination.

GENERAL GEOLOGY.

Rhyolite consisting of a series of superposed lava flows is the main rock of the tin-bearing area. Basalt appears in small quantities at the west end of the belt and becomes increasingly prominent farther west. Alluvial washes, so characteristic of the Nevada region, are amassed along the base of the range, and in places they carry wood tin.

RHYOLITE.

Rhyolite is the predominant rock of the region. It makes up nearly all the main tin-bearing range, as well as the northern extension of Shoshone Mesa, and, as shown by King,¹ is part of one of the largest areas of rhyolite found by the Fortieth Parallel Survey, an area aggregating nearly 1,500 square miles. The thickness of the rhyolite series is thought by W. H. Emmons² to exceed 2,000 feet.

The rhyolites are monotonously alike. They are highly porphyritic lavas, light gray on fresh surfaces but rather dark on weathered surfaces, so that their rhyolitic character is not obvious in distant views. They have a strongly marked flow layering, which commonly gives them a stratified appearance. As a rule the layering stands at high angles, yet in places it changes from horizontal to vertical within short distances. This feature gives the ranges, when seen from a distance, the aspect of having an irregular and confused internal structure, and, taken in connection with the petrographic uniformity of the rocks, makes it impossible without close study to determine how much the rhyolites have been faulted and tilted since they were erupted. According to Emmons³ the rhyolites are the oldest Tertiary lavas in this part of Nevada, and their eruption probably began early in Miocene time.

The rhyolites as a rule are massive porphyries crowded with phenocrysts of quartz, generally smoky, and of glassy feldspar, consisting predominantly of sanidine. The phenocrysts make up nearly one-half the bulk of the rocks, and their abundance gives the

¹ King, Clarence, *Systematic geology*: U. S. Geol. Expl. 40th Par. Rept., vol. 1, p. 624, 1878.

² Emmons, W. H., *A reconnaissance of some mining camps in Elko, Lander, and Eureka counties, Nev.*: U. S. Geol. Survey Bull. 408, p. 31, 1910.

³ *Idem*, p. 35.

rhyolites on casual examination somewhat the appearance of granites. Biotite and hornblende are notably absent. In texture the rhyolites are rather porous. Lithophysal structure is not uncommon, but the lithophysæ are not large. In a rhyolite of this kind that was especially examined the groundmass is composed wholly of delicate, extremely thin-walled lithophysæ averaging one-fourth inch in diameter. Flow breccias also occur in the region. In short, the rhyolites bear abundant evidence that they consist of a superposed succession of lava flows.

Under the microscope the dominant porphyritic component of the rhyolite is found to be quartz, which generally contains dihexahedral inclusions of glass, each inclosing a gas bubble. The feldspar, as is apparent to the unaided eye, proves to be mainly sanidine, whose optic axial angle is practically zero. Some oligoclase, however, averaging near $Ab_{70}An_{30}$ in composition, occurs and in some rocks is abundant enough to show that they have affinities with the group called in recent years quartz latite. The microscope shows further that, although biotite and hornblende are not recognizable in hand specimens, hornblende at least was originally present, but has been pseudomorphously altered to specular hematite. The accessory minerals apatite, titanite, and zircon are extremely rare, but specular hematite is common, although it is evidently not wholly a pyrogenic mineral. The groundmass is generally cryptocrystalline and partly spherulitic; tridymite is locally abundant.

Rhyolite from the Modoc No. 6 claim has been analyzed in part by Mr. A. A. Chambers in the laboratory of the Geological Survey.

Partial analysis of rhyolite from Lander County, Nev.

SiO ₂	76.25
CaO	.44
Na ₂ O	4.05
K ₂ O	5.18

The chemical analysis amply confirms the microscopic determination and shows that the rhyolite is a variety high in potassa, soda, and silica.

BASALT.

Basalt occurs at the extreme west end of the tin-bearing belt, where it forms a small patch over the rhyolite. It is a fine-grained, highly vesicular variety. Farther west basalt becomes more prominent. To the south, in the Shoshone Mesa, it attains a great thickness—as much as 1,500 feet. As shown by S. F. Emmons in the Fortieth Parallel Survey, the basalt flowed over and buried a surface of very irregular relief eroded in the rhyolite.

ALLUVIUM.

Alluvial washes skirt the base of the range, extending to elevations 300 to 400 feet above the valley bottom. They consist of rhyolite detritus and are rather bowldery, containing many blocks 3 to 4 feet in diameter. In places the alluvium has been channeled by storm waters to depths of 15 to 20 feet.

THE TIN-BEARING VEINS.

OCCURRENCE AND CHARACTER.

Veins carrying wood tin have been found along the south side of the range in an area that forms, roughly, an eastward-trending belt 10,000 feet long and 2,000 feet wide. The known veins are at altitudes between 5,500 and 5,700 feet. They are inclosed in rhyolite, which is petrographically alike at all the occurrences.

The veins are narrow, ranging in width from a fraction of an inch to 18 inches. They occur typically as stringers an inch or so wide, carrying wood tin and specular hematite in a gangue of chalcedony, lussatite (a form of silica resembling chalcedony), tridymite, and opal. At some places enough veinlets traverse the rhyolite to constitute stringer lodes, whose greatest thickness is 8 feet. The veins or stringers of tin ore, however, are widely spaced in these lodes, and the large quantity of barren rhyolite lying between the stringers will necessarily reduce the average tenor of the stringer lodes, if mined as a whole, to a low figure. It is doubtful whether any of the lodes now exposed will average 1 per cent of metallic tin. Not much is known concerning the linear extent or persistence of the lodes. Information on this point is most pressingly needed before the deposits can be exploited. It is clear that individual stringers are likely to prove disappointingly short.

Some brecciation accompanied the fissuring of the rhyolite, as is shown by the occurrence of angular fragments of rhyolite cemented by opal or incrustated with micaceous hematite, but it appears not to have been extensive. The minerals filling the veinlets are strictly contemporaneous, as is proved by their intergrowth and association. The wood tin was probably somewhat more copiously deposited during the early stages of vein formation. It is in places manifestly brecciated, angular particles of it being inclosed in a cement of hematite, chalcedony, and opal. This brecciation was probably not produced by movement along the fissures, but appears to be more reasonably interpreted as due to the setting of colloidal silica or to the bursting of colloidal membranes by osmotic forces, as in the classic example of the bursting of copper ferrocyanide membranes when immersed in a dilute solution of potassium ferrocyanide.

A notable feature of the deposits is the comparatively small amount of alteration of the rhyolites near the veinlets. The microscope shows that the groundmass of the rhyolite close to the ore has been wholly replaced by an aggregate of hematite, chalcedony, and other forms of silica, but the sanidine and oligoclase phenocrysts have remained intact.

From the foregoing description it appears that the deposits resemble the tin-bearing veins of Durango, Zacatecas, Guanajuato, and other Mexican States in their association with extrusive rhyolites, in that the tin-bearing mineral is exclusively wood tin, in the presence of abundant specular hematite in the ore, and in the character of the gangue, which consists chiefly of chalcedony. There are some differences, but the resemblance is close. Deposits of this type differ very widely from all other kinds of tin-bearing lodes, which are invariably associated with intrusive granite and occur either in the granite itself or in the adjacent rocks invaded by the granite. It is to be noted, however, that rhyolite has essentially the same chemical composition as granite but was erupted upon the earth's surface and has cooled under conditions widely different from those that prevailed where granites have cooled, and in consequence the rhyolite has assumed a texture widely different from that of granite.

DEVELOPMENTS.

Tin ore has been found in the rhyolite at many places along the belt. Some work has been done at eight of these places at least, and the more extensive developments are described in the following paragraphs.

The most work has been done on the Modoc No. 6 claim, which is at the west end of the tin-bearing belt, so far as it is now known. An incline, sloping 60° N., has been sunk here to a depth of 45 feet, following a stringer zone or lode about 8 feet thick. The zone has been cut off near the bottom of the incline by an irregular ill-defined fault dipping 45° S. It is apparently a normal fault, in which the hanging wall has slipped down relatively to the footwall, and the lode therefore would probably be recovered by drifting to the north. An open cut a few hundred feet east of the shaft is possibly on the eastward extension of the lode shown in the shaft, but no work has yet been done to test this possibility. Another cut has been opened about 100 feet north of the shaft on what is possibly a parallel vein. The prospects on these claims are more favorably situated topographically than any others in the tin-bearing belt, for considerable depth can be attained under the outcrops by means of tunnels.

On the Black Nugget No. 6 claim a tunnel 20 feet long, sloping into the hill at a low angle, has been driven on an irregular ledge ranging in thickness from 3 to 18 inches. This prospect is at an elevation of about 5,700 feet and is 6,000 feet east of Modoc No. 6. The vein is mineralogically noteworthy on account of its content of coarse tridymite, which forms granular aggregates as much as an inch in diameter. Specular hematite is particularly common, considerably more abundant than the associated wood tin, and fragments of rhyolite are completely incrustated by spherulitic micaceous hematite.

An open cut on the Mayflower claim, 4,000 feet east of the Black Nugget No. 6 tunnel, attains a depth of 10 feet. Here a zone 8 feet wide, showing a number of narrow, irregular stringers carrying wood tin and abundant platy hematite, is exposed. In this zone there are some angular fragments of rhyolite cemented by white opal, proving that a certain amount of brecciation accompanied the opening of the veinlets.

Although no tin ore has yet been found in place in the range southeast of the main tin-bearing belt, nevertheless evidence of mineralization of the same general character has been discovered. An open cut at an elevation of 5,600 feet in this range exposes an irregular vein, 6 inches wide at most, which stands vertical and trends at right angles to the flow structure of the inclosing rhyolites. The vein consists of specular hematite in a gangue of chalcedony, quartz, and opal.

MINERALOGY OF THE VEINS.

The wood tin in the veinlets in the rhyolites of northern Lander County, Nev., is the first recorded occurrence of this mineral in place in the United States. Of further interest is the association of the tin ore with abundant tridymite—an association apparently not heretofore observed elsewhere.

No topaz, tourmaline, or other fluorine or boron minerals were noted in these tin deposits. The minerals found in them are described in alphabetic order in the following paragraphs.

Chalcedony.—Chalcedony is a finely fibrous variety of silica that commonly occurs in spherulitic masses. To the unaided eye it appears to be the dominant gangue mineral associated with the wood tin; but under the microscope part of the fibrous silica corresponds closely to the mineral called lussatite by Mallard. The chalcedony (and probably the associated lussatite) is of distinctly bluish tinge.

Hematite.—Specular hematite is a common constituent of the tin ore, occurring intergrown with all the other minerals. It is embedded in the wood tin in amounts ranging from microscopic particles to masses that make up the larger part of the nuggets. The

banding of the wood tin invariably wraps around the inclosed plates of hematite. The specular hematite forms also solid layers, as much as an inch thick, of roughly radial structure. Single crystals, or the free ends of crystals embedded in other minerals, show complex crystalline habits and are splendidly lustrous.

Lussatite.—The name lussatite was given by Mallard¹ to a fibrous variety of silica whose average refractive index is 1.446, whose birefringence is somewhat less than that of quartz, and whose fibers are optically positive—properties that serve to distinguish it readily from chalcedony. A mineral having these properties is associated in some abundance with the tin ore at the Modoc No. 6 prospect. As seen under the microscope it is globular and is in places molded around plates of tridymite. In parallel light it resembles the opal that occurs with it; it has a well-marked concentric structure, and its refractive index is distinctly lower than that of the associated tridymite. Between crossed nicols it shows a finely fibrous spherulitic structure like chalcedony, but its elongation is optically positive; its birefringence, as determined by means of the interference color chart, is about 0.006. The mineral is therefore identified as lussatite. It occurs molded upon wood tin also and incloses specular hematite.

Opal.—Opal is the amorphous hydrated form of silica, carrying from 3 to 10 per cent of water. It is abundantly associated with the other silica minerals that form the gangue of the tin ore.

At one locality in the range an open cut has been made on a zone of highly opalized rhyolite. No tin ore, however, has been found in it. The opalized rhyolite consists essentially of milk-white opal with numerous quartz crystals scattered through it. So thoroughly was the original rhyolite altered that only the quartz phenocrysts remained intact and the remainder of the rock was transformed to opal, though the sanidine phenocrysts were in part changed to a mixture of opal and chalcedony.

Quartz.—Quartz does not occur in the tin-bearing veinlets as a constituent recognizable by the unaided eye, and it is present only in minute amount as shown by the microscope. As the most abundant porphyritic component of the rhyolites, however, it is a prominent constituent of the pre.

Sanidine.—Like the quartz, sanidine is abundantly associated with the ore as one of the prominent porphyritic constituents of the rhyolites. It resembles the quartz closely, from which, however, it is distinguished by its perfect cleavage. The sanidine, although it may occur in the ore or in close proximity to ore, shows no trace of chemical alteration.

¹ Mallard, E., Sur la lussatite, nouvelle variété minérale cristallisée de silice: Soc. franç. minéralogie Bull., vol. 13, pp. 63-66, 1890.

Tridymite.—Tridymite is a common constituent of the tin ore, but as a rule is only recognizable microscopically. It is most abundant in the Black Nugget No. 6 prospect, where it occurs in plates aggregated in radial or fan-shaped masses as much as an inch in diameter. In places it is well crystallized, showing the characteristic hexagonal plates: some of it incloses plates of hematite. To establish beyond question the identity of the mineral as tridymite, W. T. Schaller has carefully measured the refractive indices of material from the Black Nugget vein. He found that $\gamma = 1.477 \pm 0.001$ and $\alpha = 1.472 \pm 0.003$ —values that agree closely with those determined for tridymite by Mallard.

A determination of silica in the coarse platy aggregates was made by A. A. Chambers in the laboratory of the Geological Survey. He found that they contained 96.68 per cent of silica, a figure that, although determined on a mineral aggregate, compares closely with the figures listed by Hintze under analyses of tridymite, which range from 95.5 to 99.21 per cent silica. Under the microscope such tridymite aggregates are feebly birefringent and show a narrow polysynthetic lamellation like albite; a little quartz is present, which has probably inverted from the tridymite, as it has inherited the parting or twinning seams of the tridymite.

Plates of tridymite are embedded in the opal associated with the wood tin, lussatite, and chalcedony at the Modoc No. 6 claim. Long ago Rose¹ found that the opal of many localities is commonly filled with microscopic crystals of tridymite. This was proved true of opal from Silesia, Iceland, Carinthia, Hungary, and Mexico, and clearly shows the possibility of the hydrothermal origin of tridymite. These observations appear not to have been often repeated, but it is clear that tridymite is abundantly associated with opal and other forms of silica in the tin-bearing deposits of northern Nevada.

Wood tin.—The tin-bearing mineral is exclusively in the form of wood tin and invariably shows the characteristic concentric banding resembling the annual growth rings of wood. In color it ranges from dark reddish to brown. It is generally in globular masses or in the different modifications of this form that are designated botryoidal, mammillary, and reniform. These forms are, of course, best displayed in the material recovered from the gravels, where masses or nuggets weighing as much as 2 and 3 pounds have been found. As seen on polished surfaces and in thin sections, the particles of wood tin commonly contain nuclei of hematite. Some of these nuclei are surrounded by opal, then by hematite, and then by wood tin.

¹ Rose, G., Ueber das Vorkommen des Tridymits in der Natur: K.-preuss. Akad. Wiss. Berlin Monatsber, 1869, pp. 461-462, 1870.

Some angular particles of wood tin occur in the veinlets, and these appear to have originated from the bursting of colloidal membranes by osmotic forces in the manner shown by Liesegang¹ that certain seemingly brecciated agates were produced.

Under the microscope it is found that one of the causes of the banding of the wood tin is the alternation of opaque or nearly opaque bands with fairly translucent bands. The translucent bands react on polarized light, giving a shadowy extinction, suggestive of a radial fibrous structure. The ultimate origin of the banding is most probably due to rhythmic precipitation effected in colloidal stannic oxide.

A nugget of wood tin was analyzed in the laboratory of the Geological Survey, and the analysis probably represents the purest wood tin of this region. The specimen analyzed was dark red, homogeneous, and showed only faint banding; the powdered material was opaque, even the smallest particles being opaque when immersed in a liquid of refractive index 1.89. It was selected because of its freedom from inclusions of hematite.

Analysis of wood tin from Lander County, Nev.

[A. A. Chambers, analyst.]

SnO ₂	85.14
SiO ₂	1.03
Fe ₂ O ₃	13.42
MnO	.02
H ₂ O—	.20
H ₂ O+	.05
	99.86

The analysis shows that the wood tin is highly ferriferous, comparable in this respect to the Mexican wood tin, and contains 67.06 per cent of metallic tin. The ferric oxide is surely an integral part of the mineral. The analysis shows further that the wood tin contains no deleterious constituents, such as arsenic or antimony.

The only previously recorded occurrence of a tin mineral in Nevada is that by Hoffman,² who briefly mentions that "small crystals of cassiterite" are occasionally found in the Tuscarora placer mines. Tuscarora is 45 miles northeast of the tin-bearing area recently found, and as similar rhyolites of the same age occur there it is possible that the stream tin was derived from veinlets like those described in this report.

The simplest test for wood tin, or for cassiterite, which is the commoner form of the oxide of tin occurring in nature, is to place

¹ Liesegang, R. E., *Ein Membrantrümmer-Achat*: *Centralbl. Mineralogie*, 1912, pp. 65-67.

² Hoffman, W. J., *On the mineralogy of Nevada*: U. S. Geol. and Geog. Surv. Terr. Bull., vol. 4, p. 734, 1878.

the mineral in hydrochloric or sulphuric acid with zinc, preferably granulated zinc, for it is necessary that the mineral and the zinc should be in contact while the acid is acting on them. Immersion for a few minutes is ample, and if the mineral tested is wood tin or cassiterite it will be coated with tin, whose characteristic metallic appearance can be brought out by rubbing with a soft cloth or with the fingers.

ORIGIN OF THE VEINS.

Wood tin has been generally regarded as of secondary origin ever since Stelzner¹ showed that its abundance in the Bolivian deposits is due to the action of descending solutions, whose tin was derived from the oxidation of stannite or other tin-bearing sulphide. This explanation is doubtless correct in so far as it applies to the Bolivian deposits. Those who have described the Mexican deposits, in which the ore mineral is wood tin, do not explicitly consider the question whether the wood tin has been deposited from ascending thermal solutions or from descending oxidizing waters. The wood tin in the Nevada deposits, however, is clearly of hydrothermal origin, as is definitely shown by the intimate intergrowth of tridymite with the opal and hematite associated with it. Tridymite has been repeatedly synthesized in aqueous solutions at temperatures between 300° and 400° C. On the other hand, the lowest known temperature at which it forms in nature is 73° C., the temperature of the hot springs at Plombières, where Daubrée² found tridymite plates inclosed in the hyalite that had formed in the pores of the Roman bricks altered by the hot waters. Experiment and observation thus combine to prove that tridymite may be of hydrothermal origin, and as it occurs together with opal, lussatite, and chalcedony in the tin-bearing veinlets it affords evidence that they were all deposited from hot waters. The wood tin was deposited in the colloidal condition, like the associated chalcedony and opal, and its deposition in this form is doubtless the geologic expression of the strong chemical analogy between tin and silicon.

The fissures in which the wood tin occurs were opened by stresses that were accompanied by movement sufficient to brecciate slightly the adjoining rhyolite; at least this is true of some of the fissures, and from this it follows that the veins occupying such fissures are not merely fillings of joints or shrinkage cracks.

It is concluded, therefore, that the veins were formed by ascending hot waters soon after the eruption of the rhyolites; that these

¹ Stelzner, A. W., *Die Silber-Zinnerzlagertstätten Bolivias*: Deutsche geol. Gesell. Zeitschr., Band 49, p. 122, 1897.

² Daubrée, A., *Sur la présence de la tridymite dans les briques zéolithiques de Plombières*: Soc. géol. France Bull., 3d ser., vol. 4, p. 523, 1876; *Études synthétiques de géologie expérimentale*, p. 195, 1879.

waters deposited the wood tin and associated minerals in channels formed by dynamic action; and that it is reasonable to expect that along the more strongly fissured zones the ore will persist in depth.

PLACER TIN.

The examination of the occurrence of the wood tin in place in the rhyolites leaves a strong impression that the range is an ample source for placer tin. Certainly the relatively small amount of prospecting already done has disclosed more deposits in bedrock than have been discovered, for example, in the drainage area of Buck Creek, Alaska, whose placers are now being profitably worked; but this abundance, although highly favorable to the accumulation of workable placers, is only one of several conditions necessary for their formation. Large amounts of alluvium lie on the south flank of the range and should be carefully examined as to their content to the cubic yard and the quantity available. The placers will be difficult to work on account of the coarse gravels, boulders 3 and 4 feet in diameter being common, and because of the lack of water supply. It may be necessary to work them by dry placering.

A small attempt at placer mining was made in the spring of this year by the use of the very scant supply of water available from melting snow. A short sluice box was set up in a steep gulch only a few yards below the cliffs against which it heads—obviously a place unsuitable for commercial operations—and considerable wood tin, mixed with perfectly faceted hematite, was recovered, sufficient to show that the gravel here is richly tin bearing.

Some float wood tin has also been found in the range west of Warm Spring, in the northern extension of Shoshone Mesa. It has not yet been traced to its source in bedrock.

PRACTICAL CONSIDERATIONS.

That the tin ore occurs in narrow veins inclosed in rhyolite lavas of Tertiary age stamps the deposits immediately, as already pointed out, as belonging to a type heretofore only known from Mexico. Unfortunately, the Mexican deposits have not yielded largely or steadily, because they are buncy and discontinuous. The greatest depth to which any vein has been worked is 200 feet. The placers, however, according to the most recent description,¹ hold promise of economic value. The resemblance of the Nevadan to the Mexican tin veins will therefore, it must be recognized, create a presumption against their value and will doubtless compel the discoverers to develop the deposits more extensively than is generally necessary.

¹ Wittich, E., Zinnerze in der Sierra von Guanajuato, Mexico: Zeitschr. prakt. Geologie, Jahrg. 18, pp. 121-123, 1910.

In view of the scant knowledge of the Mexican veins, especially of matters that are essential to the valuation of similar deposits occurring elsewhere, it would be idle to draw too heavily upon mere resemblance. The Nevada deposits should be prospected and developed on their own merit. What appears necessary to be done now is to concentrate development at a few of the most favorable outcrops. The prospecting so far done proves that tin ore occurs in bedrock at many places but has not been of the kind adequately to determine the continuity of any one deposit along its strike; in fact, the number of openings at widely separated points is likely to create the adverse impression that the tin ore invariably occurs in small discontinuous veinlets. It is necessary, therefore, to determine whether some, at least, of the stringer zones or lodes persist along the strike and whether they continue in depth; in short, it must be shown that ore is available in commercial quantities.

As the price of tin fluctuates rather abruptly and widely, it will be advisable to base all estimates of the value of tin ore on the possible minimum price of the metal, namely 30 cents a pound, as indicated by the average annual prices since 1905, which have ranged from 29.54 to 46.43 cents. It is probable that only ore carrying in excess of 1 per cent of metallic tin can be worked profitably.

The known tin-bearing belt is a small fraction of the great area of 1,500 square miles or more underlain by rhyolites similar to those associated with the tin ore in northern Lander County. This rhyolitic area extends at least as far north as the Nevada-Idaho State line. Clearly it is a region that merits further attention from the prospector, especially such parts as have been but superficially examined because barren of precious-metal deposits.

SUMMARY.

The tin ore of northern Lander County, Nev., occurs in a series of rhyolite flows of middle Tertiary age. The stanniferous mineral is exclusively wood tin, which is inclosed in narrow veinlets together with specular hematite, chalcedony, lussatite, tridymite, and opal. The veinlets are sufficiently numerous in places to form low-grade lodes, but because of the small development so far done not much is known of the persistence and tenor of these lodes. The deposits are clearly of hydrothermal origin, and consequently the deposition of the tin ore in the veinlets is in nowise due to the action of descending surface waters.

The deposits resemble closely those of the Mexican States of Durango, Zacatecas, and Guanajuato, and with the exception of these they are wholly unlike all other tin deposits, which are generally associated with intrusive granites. Tin ore has been found

in place at a number of localities over a considerable area, and, furthermore, placer tin ore has been found not only in all the gulches heading in this area but also in some of those in the northern end of Shoshone Mesa.

In conclusion, it is believed that the indications of the stronger lodes, taken in connection with their geology, are such as to justify further exploration; that the rhyolite area, of which the known tin belt forms but a small part, deserves further prospecting; and that the placers should be carefully examined to determine their economic possibilities.



DEPARTMENT OF THE INTERIOR

FRANKLIN K. LANE, Secretary

UNITED STATES GEOLOGICAL SURVEY

GEORGE OTIS SMITH, Director

Bulletin 640—H

GYPSUM IN THE SOUTHERN PART OF
THE BIGHORN MOUNTAINS
WYOMING

BY

CHARLES T. LUPTON

AND

D. DALE CONDIT

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GYPSUM IN THE SOUTHERN PART OF THE BIGHORN MOUNTAINS, WYOMING.

By CHARLES T. LUPTON and D. DALE CONDIT.

INTRODUCTION.

Gypsum has been known in a belt of rocks surrounding the Bighorn and Owl Creek mountains, Wyoming, from the early days of exploration. The amount of this material at several places is great, but owing to the slight demand little attention has been given to the use of it until the last few years. It is quarried at two or three places in the Bighorn Basin and is being manufactured into stucco building blocks at Basin and Greybull. In the vicinity of Sheep Mountain the gypsum-bearing rocks are close to the railroad, and here the only development has taken place. The beds containing gypsum are crossed by the railroad in the vicinity of Thermopolis, but no quarrying on a commercial scale has been done there.

The gypsum occurs at two horizons, the upper at or near the top of the Chugwater formation (red beds) and the other in the upper part of the Embar formation. Only the upper bed, however, is of economic importance at Sheep Mountain and in the vicinity of Thermopolis.

The field work on which this paper is based was done during the seasons of 1914 and 1915. Mr. Condit examined the Embar gypsum in connection with his investigations of the phosphate deposits in this general region in 1915, and Mr. Lupton examined all the sections of gypsum at the top of the Chugwater formation here described, incidentally to oil and gas investigations in the eastern and southern parts of the Bighorn Basin in 1914 and 1915. Mr. Lupton also examined the Embar gypsum a few miles south of Hyattville, near the Ziesman ranch, where he obtained a sample of gypsum for analysis.

GEOGRAPHY.

LOCATION AND EXTENT.

The gypsum-bearing rocks described were examined in a general way in an area extending from Sheep Mountain, a few miles north of Greybull, southeast around the edge of the basin and west as far as Bighorn River near Thermopolis. On the east side of the Bighorn Mountains the Embar gypsum was examined from a point near

Buffalo south to the locality where the Bighorn Range merges with the Owl Creek Range. The area represented on Plate III is about 90 miles from north to south and 75 miles from east to west.

ACCESSIBILITY.

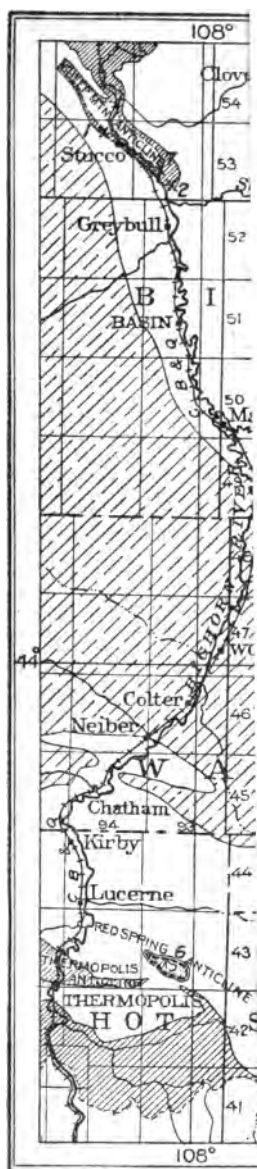
Much of the gypsum herein described lies at a considerable distance from the railroad and will probably not be exploited for decades, but it is worth while to have an inventory of such deposits for use when the demand for them becomes greater.

The deposits of gypsum in the Bighorn Basin that are at present most easily accessible are those that crop out in the vicinity of Sheep Mountain and near Thermopolis, where the Embar and Chugwater formations are brought to the surface by the prominent Sheep Mountain and Thermopolis anticlines. In the vicinity of Sheep Mountain the gypsum is being mined near the railroad and is transported by rail to Basin, 18 miles to the south, where it is manufactured into blocks for use in building. It seems safe to predict that deposits at some distance from the railroad will not be developed until the beds adjacent to the railroad have been nearly exhausted. At present the gypsum is quarried. It is a question whether it will not be more economical to extend the workings underground at the localities close to the railroad than to open new quarries at points more remote from transportation facilities.

The gypsum occurring at the top of the Chugwater formation along the southeast margin of the Bighorn Basin will probably be next developed, especially if a railroad should be constructed up the valley of No Wood Creek from Manderson, where this stream joins Bighorn River. Such a branch line would not only open up a rich territory but would also hasten the development of the gypsum beds that crop out in and near this valley. Good wagon roads extend up No Wood Valley and across country from Worland to Tensleep, but it is very doubtful whether the gypsum can profitably be hauled in wagons this distance (30 or 35 miles) to the railroad. The deposits of gypsum on the east and southeast sides of the Bighorn Mountains, although unusually thick, are of the least value on account of their remoteness from any present or prospective railroad line.

CLIMATE.

The climate of the Bighorn Basin is semiarid. Records of temperature and precipitation kept at a number of places for a period of several years show that the border of the basin, where most of the gypsum beds crop out, receives a rainfall of 11 to 12 inches annually, and that the interior receives about 6 inches. The interior is colder than the border in winter and warmer in summer. The greatest variation in temperature has been recorded at Basin, where, accord-



TERTIARY



Wasatch formation
(clay, sandstone,
and marls)

MAP SHOWING OUT

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ing to observations extending through a period of 11 years, the thermometer has registered a minimum of 51° below zero in February and a maximum of 110° above zero in June, July, and August.

The variations of temperature, as well as of rainfall, necessarily will have an effect on the cost of development of the gypsum in this region, as for two or three months during the winter work can not be carried on unless the gypsum is mined under cover.

SURFACE FEATURES.

The area represented on the accompanying map (Pl. III) includes the southern part of the Bighorn Mountains and the adjacent part of the Bighorn Basin, to the west. The Bighorn Range attains a maximum altitude of about 14,000 feet at Cloud Peak, and the average altitude along the crest is a little more than 8,000 feet. The country along the base of the mountains, where the gypsum beds crop out, is from 4,000 to 6,000 feet above sea level. Both the mountain slopes and the adjacent foothills furnish summer range for great numbers of sheep. The mountains, except in the more rugged parts, are not thickly forested.

Near the top of the Chugwater formation is a prominent wall of red sandstone and shale which serves as a good marker for the overlying gypsum beds. It extends almost throughout the Chugwater outcrop, forming a prominent hogback near the crest of which the gypsum beds occur. The sandstone wall facing the mountains is separated from them by a valley eroded 200 to 500 feet deep in the softer beds of sandstone and shale forming the lower part of the Chugwater red beds. On the mountainward side of this valley is the Embar formation, near the top of which occur gypsum beds along the Bighorn Mountain front.

Most of the streams flowing from the mountain front cut directly across the sandstone hogback in the red beds or run for a short distance parallel to it before crossing toward the plains. The principal drainage line of the Bighorn Basin is Bighorn River. Tributary to it are Shell Creek, Paintrock Creek, No Wood Creek, Otter Creek, and Bridger Creek, all of which offer easy routes of access to the outcrops of the gypsum beds. The principal streams on the east side of the Bighorn Mountains are Crazy Woman Creek, North Fork of Powder River, Middle Fork of Powder River, and Buffalo Fork, all of which flow across the gypsum-bearing beds.

GEOLOGY.

GENERAL SECTION.

The rocks exposed in the region covered by this report range in age from pre-Cambrian to Quaternary. The Embar and Chugwater formations, which contain the gypsum beds, are described in detail.

Their positions with reference to other formations are represented in the following table. Detailed descriptions of the entire sequence of formations are given by Darton,¹ Fisher,² and Hewett and Lupton.³

Stratigraphic sequence of formations exposed in Bighorn Mountains and Bighorn Basin, Wyo.

Quaternary:

- Alluvium.
- Later terrace gravel.
- Early terrace gravel.
- Hot-spring deposits.

Unconformity.

Tertiary:

- Wasatch formation.
- Fort Union formation.

Unconformity

Tertiary (?):

- Lance formation.

Cretaceous:

- Meeteetse formation.
- Mesaverde formation.
- Cody shale.
- Frontier formation.
- Mowry shale.
- Thermopolis shale.
- Cloverly formation.

Unconformity.

Cretaceous (?):

- Morrison formation.

Jurassic:

- Sundance formation.

Triassic and Carboniferous:

- Chugwater formation (Triassic, Permian, and Pennsylvanian beds of red color, almost wholly nonmarine, in part overlying and in part contemporaneous with and grading horizontally into the marine Embar formation).
- Embar formation (Lower Triassic, Permian, and Pennsylvanian marine beds of gray and greenish color, together with thick red beds).
- Tensleep sandstone (Pennsylvanian).
- Amsden formation (chiefly Pennsylvanian).
- Madison limestone (Mississippian).

Ordovician:

- Bighorn dolomite.

Cambrian:

- Deadwood formation.

Pre-Cambrian:

- Granite.

GYPSUM-BEARING FORMATIONS.

CHUGWATER FORMATION.

The Chugwater formation (red beds) was named by Darton from Chugwater Creek, in the Laramie Mountain region, Wyo., where it is

¹ Darton, N. H., *Geology of the Bighorn Mountains*: U. S. Geol. Survey Prof. Paper 51, pp. 13-91, 1906.

² Fisher, C. A., *Geology and water resources of the Bighorn Basin, Wyo.*: U. S. Geol. Survey Prof. Paper 53, pp. 8-36, 1906.

³ Hewett, D. F., and Lupton, C. T., *Anticlines in the southern part of the Bighorn Basin, Wyo.*: U. S. Geol. Survey Bulletin—(in preparation).

well exposed. It is presumably for the most part of Triassic age, although but few fossils have been found in it in the Bighorn Basin. It consists principally of red sandstones and shales, with beds of gypsum and gypsiferous limestone near the top. The lower part is predominantly shaly, the middle sandy, and the upper calcareous and gypsiferous. It ranges in thickness from 600 to 1,000 feet and in most places finds topographic expression in a valley and one or more flanking hogback ridges produced by the more resistant beds near the top of the formation. Its outcrop around the Black Hills is described as the Red Valley. The same term is applicable to its outcrop in the Bighorn Mountain region.

The formation is well exposed along the east and south sides of the Bighorn Basin, except in the vicinity of Lysite Mountain, 20 to 25 miles east of Bighorn River canyon, where the Chugwater is overlain by Tertiary beds. On the east side of the Bighorn Mountains it is generally well exposed, but at the south end of these mountains and also south of the Owl Creek Range it is concealed over large areas by Tertiary beds.

Gypsum is present near the top of the formation at nearly every place where it has been examined. The gypsum beds lie from 15 to 120 feet below the top of the formation, as shown by the sections of gypsum and associated rocks on Plate V (p. 146).

Both Darton¹ and Fisher² were of the opinion that gypsum beds are included in the lower part of the formation, but the work of Condit in his study of the phosphate deposits of the Owl Creek and Bighorn mountains has proved that the gypsum beds heretofore thought to be included in the lower part of the Chugwater are in the upper part of the Embar formation. The conclusions reached by Darton and Fisher, whose work was of the reconnaissance type, were natural, for the beds that include the gypsum in what they regarded as the lower part of the Chugwater are lithologically very similar to the overlying beds, which without question belong to the Chugwater.

EMBAR FORMATION.

The term Embar designates strata ranging in age from Pennsylvanian to early Triassic, lying between the Tensleep sandstone and Chugwater red beds in central Wyoming. The name was introduced by Darton³ for these beds in the Owl Creek Mountains, and the type locality is at Embar post office, on Owl Creek, some 25 miles west from Thermopolis. The formation has in recent years attracted

¹ Darton, N. H., *op. cit.*, p. 37.

² Fisher, C. A., *Geology and water resources of the Bighorn Basin, Wyo.*: U. S. Geol. Survey Prof. Paper 53, p. 18, 1906.

³ Darton, N. H., *op. cit.*, p. 35.

attention on account of its phosphate beds, which have been traced throughout the Wind River and Owl Creek mountains.

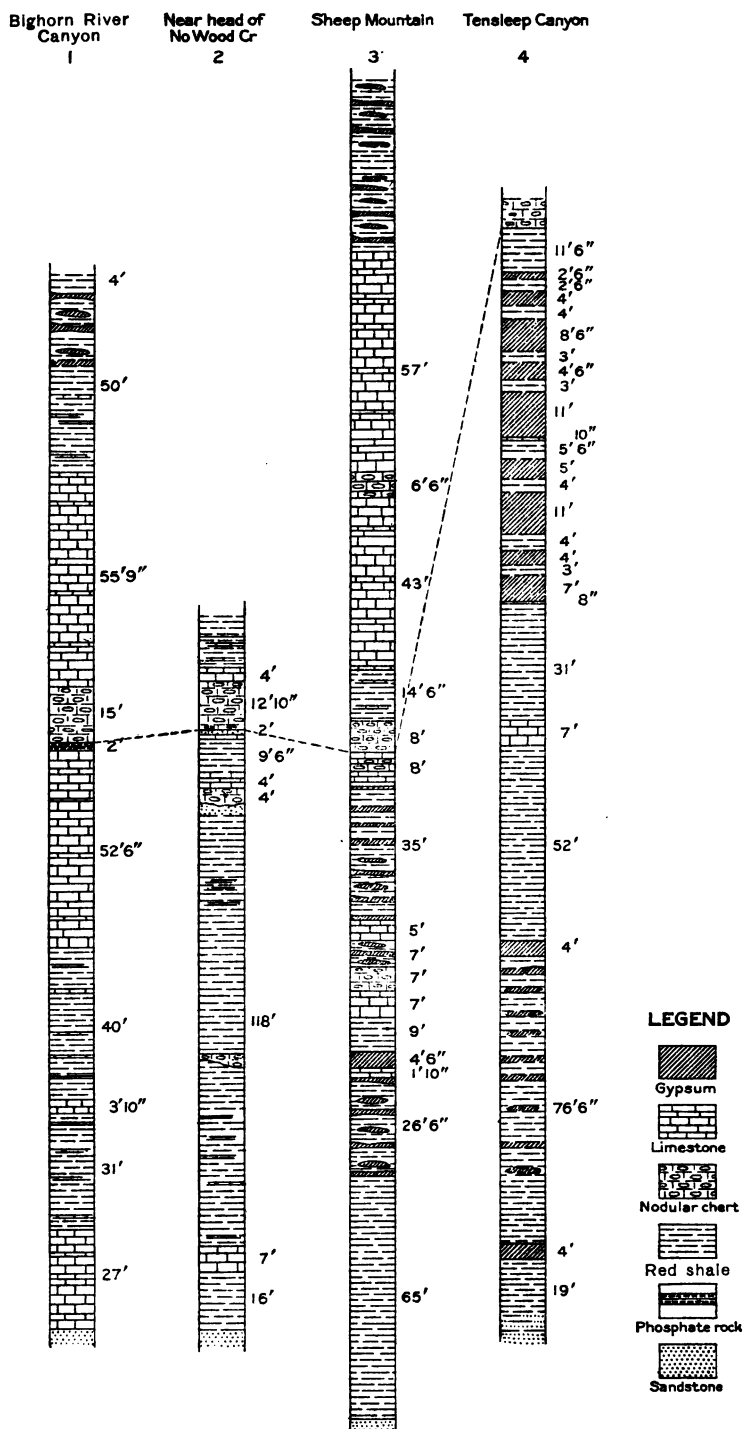
Blackwelder¹ has recommended that the Embar be divided into two formations. For the upper shaly portion he suggests the name Dinwoody, from Dinwoody Lake, in the Wind River Mountains, and for the lower portion, consisting largely of fossiliferous limestone, the name Park City, in accordance with the use of that name for beds in Utah, with which the lower portion of the Embar is correlated. These names have been approved by the United States Geological Survey, but over a part of the area considered in this paper the Dinwoody and Park City units are not recognizable, and therefore it is considered advisable to designate the beds collectively by the old name Embar.

The Embar deposits in the Wind River and Owl Creek mountains consist largely of limestone, with a lesser amount of calcareous or sandy shale and chert. Fossils are abundant, and the strata have every appearance of being almost entirely marine deposits. When followed eastward into the Bighorn Mountains, the deposits are found to undergo a gradual transformation which may be summarized as follows: (1) Increase in thickness; (2) lithologic changes, including thinning of limestone beds and an increase in the amount of shale, almost entirely of red color; (3) the appearance of beds of massive clean gypsum in all but the basal portion; (4) the gradual eastward disappearance of marine fossils except in basal beds; (5) the prevalence of calcareous conglomerate at the principal limestone horizons; and (6) the disappearance of concentrated beds of phosphate rock. With these changes the Embar as found in the Bighorn Mountains so little resembles the typical Embar of the Owl Creek Mountains that their relation would hardly be suspected if it had not been demonstrated by tracing the outcrop continuously from one region to the other.

The lithologic character of the Embar in the Owl Creek Mountains is illustrated by the section measured at Bighorn River canyon. (See Pl. IV.) The upper portion, about 60 feet thick, which lies immediately beneath the Chugwater red beds and which Blackwelder called the Dinwoody formation, consists largely of greenish to brownish shale containing layers of impure gypsum intimately interbedded with the shale.

Beneath the shale is a gray limestone member so much more resistant than beds in overlying formations that it extends far up the mountain side, forming the dip slopes so conspicuous in the vicinity of Bighorn River canyon south of Thermopolis. Beneath this

¹ Condit, D. D., Relations of the Embar and Chugwater formations in central Wyoming: U. S. Geol. Survey Prof. Paper 98, pp. 263-270, 1916 (Prof. Paper 98-O).



SECTIONS OF EMBAR FORMATION AT BIGHORN RIVER CANYON, HEAD OF NO WOOD CREEK, SHEEP MOUNTAIN ANTICLINE, AND TENSLEEP CANYON, WYO.

limestone lies shaly chert, which is underlain by a persistent bed of phosphate rock, 1 foot to 3 feet thick, throughout the Owl Creek Range. The lower half of the Embar contains considerable shale and limestone of variable character. The principal limestone member lies at or near the base, resting on the Tensleep sandstone.

A section measured in T. 41 N., R. 89 W., along a ravine near the head of No Wood Creek (see Pl. IV), illustrates the character of the Embar beds that are transitional from the marine limestone of the Owl Creek Mountains to the shaly gypseous red beds of the Bighorn Mountain region. Above the middle is the usual chert and some limestone, practically devoid of fossils, but the lower part is almost entirely red shale.

The section measured at Tensleep Canyon, in T. 47 N., R. 88 W., near Burke's ranch, is representative of the Embar beds along the Bighorn Mountain front. The thickness here is, however, somewhat greater than usual, being at least 350 feet. Limestone, except for a few thin dolomitic layers, is lacking. In the upper part is the persistent pinkish to greenish nodular chert. Beneath the chert is much gypsum in massive white courses interbedded with red shale, the combined thickness being nearly 100 feet. A few thin layers of gypsum are also distributed at random through the lower part of the section, down to a horizon within about 20 feet of the Tensleep sandstone.

The Embar along the Bighorn Mountains, as would be expected from its shaly character, is physiographically weak and does not extend nearly so far up the mountain slopes as it does in the Owl Creek Mountains. In fact, its lithologic character and physiographic expression are so similar to those of the overlying Chugwater red beds that few distinctively Embar features are recognizable.

The gypsum, on account of its comparative solubility, has been removed from the upper parts of the hills along the mountain base where the relief is considerable, and the thickest exposures are found at the lowest accessible points. Even in level tracts along the valleys partial removal is locally indicated by cavernous openings and sink holes into which streams disappear. The evidence of extensive solution of the gypsum deposits along the Bighorn Mountains raises the question whether beds of certain salines may have been deposited along with the gypsum and whether the removal of these soluble deposits may not have caused the general brecciated, distorted character of the Embar beds noticed at so many localities.

In addition to irregularities in the gypsum deposits that are due to solution, they show great variations that are attributed entirely to differences in conditions of deposition. Thick deposits followed a distance of only a mile or so along the outcrop are commonly found

to disappear and give place to calcareous breccias and conglomerates, succeeded in turn by more gypsum. These features are indicative of the conditions under which deposition of the lenses of gypsum probably took place.

STRUCTURE.

The dominant structural feature of the region is of course the Bighorn uplift, on the flanks of which the beds are inclined at different angles. Those on the west slope dip steeply in places, as in the vicinity of Horse Creek canyon southeast of Cloverly, where the dip is more than 50° . Elsewhere, as in the vicinity of Redbank, the dip is low and the formations accordingly form long dip slopes on the mountain front.

The westward dip of the beds into the basin is varied at numerous localities by folds, three of which are so large that along them are exposed gypsum-bearing beds which in the adjacent synclines lie hundreds of feet below the surface. The most profound of these folds in the Bighorn Basin is the Sheep Mountain anticline, which exposes strata down nearly to the base of the Madison limestone. Other prominent folds are the Thermopolis and Red Spring anticlines, at the south side of the Bighorn Basin, parallel to the Owl Creek Range. No such prominent anticlines are found in the region east of the Bighorn Range, and in none of the folds away from the mountain front are the red beds exposed.

THE GYPSUM.

GENERAL FEATURES OF OCCURRENCE.

The gypsum described in this report is so finely crystalline that the individual granules are not recognizable without the aid of a microscope. It is mainly white and fairly hard except near the surface, where it is somewhat weathered. Certain layers have a flesh-pink or yellowish color caused by the inclusion of mechanical sediments or by mineral stains.

The gypsum is fairly soluble in water and as a rule softer than the sandstone and shale, and therefore it is rarely well exposed. It can best be seen in places where the beds have been recently denuded by streams, or where the gypsum is well protected by sandstone and shale in the faces of cliffs. In many places the gypsum has been partly dissolved and the overlying beds have become twisted and distorted by settling, so that they do not conform with the beds below the gypsum.

The varying thickness and number of the beds of gypsum suggest that they were not deposited as continuous sheets over the region, but rather formed as lenses in isolated bodies of water along the margin of a sea that was subject to intermittent fluctuations in level.

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Partial exposures of the gypsum can be observed at almost every place where the top of the Chugwater and the top of the Embar are exposed. At only a few places, however, is it possible to measure a complete section of the gypsum beds, because of slumps, slides, and talus, which partly or wholly obscure the beds.

GYPSUM IN THE CHUGWATER FORMATION.

The sections of gypsum measured in the Bighorn Basin and east of the Bighorn Mountains are shown graphically on Plate V, arranged in order from north to south. The sections of gypsum in the Chugwater formation are Nos. 1 to 6 and the sections in the Embar formation are Nos. 7 to 13.

GRAPHIC SECTIONS.

In the sections on Plate V, showing the gypsum in the upper part of the Chugwater formation, the highest beds include the top of the Chugwater formation. It may be observed from these sections that the gypsum is not everywhere found at the same distance below the top of the formation and also that the gypsum in sections 1, 2, and 3 is included in two to eight beds of varying thickness, whereas in sections 4, 5, and 6 most of the gypsum is in one bed of considerable thickness, ranging from 42 to 74 feet. Sections 1, 5, and 6 show that some limestone is present in the top of the Chugwater formation, but limestone is not noticeable in the other sections.

NEAR STUCCO.

Gypsum is being mined from the upper part of the Chugwater formation at a point about half a mile west of Stucco (section 1, Pl. V), a flag station on the Chicago, Burlington & Quincy Railroad about 8 miles northwest of Greybull. Although the gypsum at this locality is not in one persistent bed, yet its nearness to the railroad enables the owners to mine it with profit. The gypsum is sent by rail to Basin, 18 miles to the south, where it is manufactured into stucco blocks for building. Information regarding this plant is given below under "Development."

A sample of gypsum was collected near this quarry and analyzed in the chemical laboratory of the United States Geological Survey.

Partial analysis of gypsum from deposit near Stucco, about 8 miles north of Greybull.

[W. C. Wheeler, analyst.]

Lime (CaO).....	33.74
Sulphur trioxide (SO ₃).....	43.92
Water driven off at 300° C.....	19.50
Chlorine (Cl).....	None.
Silica (SiO ₂).....	.01
Manganese oxide (MnO).....	.98
Iron and alumina mixed (Al ₂ O ₃ and Fe ₂ O ₃).....	.17

The percentages of lime, sulphur trioxide, and water given in the analysis closely approach those of pure gypsum. The percentage of lime, however, is a little higher than normal, and that of sulphur trioxide more than 2 per cent lower. The water is more than 1 per cent less than that of pure gypsum. The excess of lime and the presence of carbon dioxide, determined qualitatively, indicate that a small amount of calcium carbonate is present.

NEAR GREYBULL.

The gypsum at the top of the Chugwater formation is fairly well exposed near the south end of Sheep Mountain, about 2 miles north of Greybull, on the north side of Shell Creek (section 2, Pl. V). The highest gypsum noted in this section is about 120 feet below the top of the formation. In all, 47 feet of gypsum is exposed. The total amount may be greater than this, however, as part of the section was concealed. This gypsum is similar in appearance to that at Stucco, therefore it is believed that a chemical analysis would be very similar to the one given above.

NEAR HYATTVILLE.

At a point about 5 miles south of Hyattville and half a mile west of the Hyattville-Tensleep road, a section (section 3, Pl. V) of the gypsum at the top of the Chugwater formation was measured. At this locality the gypsum occurs in seven beds, ranging in thickness from 1 foot 8 inches to 13 feet. The total thickness of the gypsum exposed is about 43 feet.

Most of the gypsum at this place is pure white, but some of it is brownish gray, with a red stain on the outside from adjacent beds of red sandy shale. An analysis of a sample of the pure-white gypsum of this place is given below.

Partial analysis of gypsum from the NW. $\frac{1}{4}$ NW. $\frac{1}{4}$ sec. 33, T. 49 N., R. 89 W., at a point about 5 miles southeast of Hyattville.

[W. C. Wheeler, analyst.]

Lime (CaO).....	32.92
Sulphur trioxide (SO ₃).....	45.74
Water driven off at 300° C.....	19.99
Chlorine (Cl).....	None.
Silica (SiO ₂).....	.05
Manganese oxide (MnO).....	.44
Iron and alumina mixed (Al ₂ O ₃ and Fe ₂ O ₃).....	.03

The percentages of lime, sulphur trioxide, and water given in this analysis closely approach those of theoretically pure gypsum, the lime being a little higher and the sulphur trioxide more than 2 per cent lower. The facts that the lime is more than 1 per cent higher than is present in pure gypsum and that carbon dioxide also is present in small amount suggest strongly that some of the lime is in the form of carbonate.

NEAR TENSLEEP.

The gypsum near the top of the Chugwater formation was measured at a point about 2 miles northwest of Tensleep (section 4, Pl. V), on the west side of No Wood Creek and the north side of the Tensleep-Worland road. At this locality the gypsum is higher in the Chugwater formation than at any other place on the east and south sides of the Bighorn Basin, being separated from the top of the formation by only 15 feet of red shale, as shown by the section. The gypsum is thicker here than at any other outcrop of the Chugwater beds described in this paper, there being 74 feet, of which the upper 20 feet is impure.

Gypsum in this locality has not been quarried and probably will not be until a railroad is constructed up No Wood Creek.

NEAR BIGTRAILS.

The gypsum in the upper part of the Chugwater was examined in detail near Bigtrails (section 5, Pl. V), at the mouth of Buffalo Creek, a western tributary of No Wood Creek, which joins that stream in sec. 1, T. 44 N., R. 88 W. At this place the gypsum is in one bed 48 feet thick, lying 50 feet below the top of the Chugwater formation. It is mainly white and very pure. The overlying rocks, as shown on Plate V, contain three beds of limestone. This is an unusual feature along the east side of the basin, no limestone having been observed at this horizon between this locality and Stucco, north of Greybull. (See section 1, Pl. V.)

Owing to the presence of excellent building stone near by, to the comparatively small population of the region, and to the long distance from railroad transportation, the development of the gypsum at this locality is very remote.

EAST OF THERMOPOLIS.

The gypsum in the upper part of the Chugwater formation is fairly well exposed in the Red Spring anticline, a few miles east of Thermopolis. Section 6, Plate V, is believed to represent an average thickness of the gypsum, which is in two beds. The upper bed, 10 feet thick, lies about 33 feet above the lower bed, which is 42 feet thick. It crops out near the top of an inward-facing wall of alternating red sandstones and shales, which are exposed around the anticline. Any gypsum mined in this locality will necessarily be removed from the depression in which it crops out by way of the narrow canyons of intermittent tributaries of Kirby Creek that are cut through the prominent wall or rim. In view of the large quantities of gypsum in the Thermopolis anticline along Bighorn River, and in the Sheep Mountain anticline, both near the Chicago, Burlington

& Quincy Railroad, it is doubtful whether the gypsum in the Red Spring anticline will be mined until these deposits adjacent to the railroad are for the most part exhausted.

Below is given the analysis of a sample of gypsum collected from the north flank of the Red Spring anticline near the top of the Chugwater formation.

Partial analysis of gypsum from north flank of Red Spring anticline, in the NW. $\frac{1}{4}$ SW. $\frac{1}{4}$ sec. 21, T. 43 N., R. 93 W.

[W. C. Wheeler, analyst.]

Lime (CaO).....	34.20
Sulphur trioxide (SO ₃).....	45.50
Water driven off at 300° C.....	20.00
Chlorine (Cl).....	None.
Silica (SiO ₂).....	.25
Manganese oxide (MnO).....	None.
Iron and alumina mixed (Al ₂ O ₃ and Fe ₂ O ₃)	.10

As compared with pure gypsum, this sample contains 1.6 per cent more of lime and 1 per cent less of sulphur trioxide. Its content of water is slightly lower than that of pure gypsum. The excess of lime and the presence of carbon dioxide, qualitatively determined, suggest the presence of calcium carbonate.

GYPSUM IN THE EMBAR FORMATION.

GRAPHIC SECTIONS.

Localities where the Embar formation was examined and gypsum beds measured or found to be lacking are marked on the map and designated by Nos. 7 to 13, which apply to the sections represented on Plate V. The localities lie on both the east and west slopes of the Bighorn Range and include the Sheep Mountain anticline near Greybull. They are described below in order from north to south.

SHEEP MOUNTAIN ANTICLINE NEAR GREYBULL.

The most valuable gypsum beds in the Sheep Mountain anticline lie within the upper portion of the Chugwater formation, but the Embar contains a few beds 3 to 4 feet thick where examined at a point along the southwest base of the mountain, about 2 miles north of the mouth of Shell Creek. In addition to the several thin pure layers there are abundant irregular veinlets of coarsely crystalline gypsum that form a network in the red shales. The gypsiferous portion of the formation is represented in section 7, Plate V. It is noteworthy that on the summit of the mountain due east from the point above described and some 1,000 feet higher, where the same strata are present as an erosion remnant along the crest of the anticline, the gypsum has been entirely removed by solution.

Along the base of the mountain near the river and immediately beneath the red beds of the Chugwater formation, there is about 60 feet of bluish-gray shale, weathering to ochereous brown. This shale, the equivalent of the Dinwoody formation of the Bighorn River canyon, contains many irregular veinlets of impure gypsum.

WEST SLOPE OF THE BIGHORN MOUNTAINS.

HORSE CREEK CANYON.

At Horse Creek canyon, in T. 54 N., R. 91 W., the mountain front is formed by bold cliffs of Tensleep sandstone inclined westward at an angle of about 55°. Fair exposures of all but the upper third of the Embar formation show no gypsum. Although this canyon is only 14 miles east of the Sheep Mountain locality described above, the Embar shows a marked transformation, there being a great increase in the proportion of red beds to limestone and a change from firm marine fossiliferous limestone layers to irregular conglomeratic vesicular limestone of tufaceous appearance.

Gypsum was not seen in the vicinity of Horse Creek canyon, but it may be present in considerable quantity. Good rock exposures are not plentiful owing to the mantle of talus at the bases of the steep mountain slopes. Fisher¹ measured a section along Shell Creek, about 5 miles southeast of Horse Creek, where he found 12 feet of gypsum 24 feet above the Tensleep sandstone. Gypsum is also reported in Red Gulch, east of Cloverly.

ZEISMAN RANCH NEAR HYATTVILLE.

Gypsum beds, probably lying in the upper part of the Embar formation, were measured by Lupton on a tributary of No Wood Creek near the Zeisman ranch, in the SE. $\frac{1}{4}$ sec. 34, T. 49 N., R. 89 W. (section 8, Pl. V). The section of the beds shows a number of layers of gypsum 4 to 10 feet thick, alternating with red shale and a few thin laminæ of limestone. One bed 10 feet thick was sampled for chemical analysis, and the results are as follows:

Analysis of gypsum from deposit near the Zeisman ranch.

[W. C. Wheeler, analyst.]

Lime (CaO).....	32.72
Sulphur trioxide (SO ₃).....	45.18
Water driven off at 300° C.....	20.03
Chlorine (Cl).....	None.
Silica (SiO ₂).....	.06
Manganese oxide (MnO).....	.42
Iron and alumina mixed (Al ₂ O ₃ and Fe ₂ O ₃).....	.05

¹ Fisher, C. A., *Geology and water resources of the Bighorn Basin, Wyo.*: U. S. Geol. Survey Prof. Paper 53, p. 19, 1906.

The percentage of lime shown by this analysis is only slightly in excess of the amount normal to pure gypsum, which is 32.60. There is a trace of carbon dioxide, indicating a small amount of calcium carbonate.

TENSLEEP CANYON.

Measurements were made near the Burke ranch, on the north side of Tensleep Creek, in T. 47 N., R. 88 W. (section 9, Pl. V), where the beds dip westward at an angle of about 10° . Section 4 in Plate IV (p. 144) is a detailed section from the Tensleep sandstone upward. Two layers of gypsum 2 feet and 4 feet thick were found in the midst of the red shale in the lower part of the formation, but the principal beds lie about 240 feet above the Tensleep sandstone. They consist of many layers interbedded with insignificant shale beds, the total thickness being about 90 feet. The gypsum is stained reddish brown on the outcrop, but beneath the surface it is snowy white and free from mechanical sediment. The texture is so fine that the glistening crystal faces are barely visible to the naked eye. The gypsum exposures in this vicinity in many respects rank among the best deposits seen in the Bighorn Mountain region.

CHERRY CREEK NEAR REDBANK.

The exposures described lie near the base of the mountain along the valley of Cherry Creek, about 2 miles southwest of Redbank, in T. 43 N., R. 87 W. (section 10, Pl. V). In this vicinity the upper limestone member of the Embar formation extends well up the mountain slopes to an altitude of nearly 7,000 feet. All the gypsum once present in the upper slopes has been dissolved away, and none is found above a certain altitude, possibly about 6,700 feet above sea level. From that altitude down the slopes gypsum is increasingly conspicuous and the thickness of the entire formation is accordingly greater than on the upper slopes.

The most valuable gypsum beds lie beneath the nodular chert in the upper part of the formation. The section on Plate V shows about 30 feet of almost continuous gypsum with a few thin layers of reddish shale. Beneath these are about eight massive gypsum beds, each 2 to 4 feet thick, scattered through an interval of about 50 feet of red shale. As followed along the strike, the beds recorded here are found to vary in thickness and to disappear within a short distance, giving place to conglomeratic limestone. A little farther along there appear other gypsum deposits of similar importance. Sections measured 1 mile apart have little similarity except that the gypsum beds occupy the same general position in the section.

VICINITY OF NO WOOD.

About 3 miles northeast of No Wood, where No Wood Creek enters the canyon, in T. 42 N., R. 88 W., the upper part of the Embar consists largely of massive beds of white gypsum many feet thick, with a few interbedded layers of red shale. About a mile southwest of the canyon, toward No Wood, the upper part of the formation shows almost no gypsum and contains an upper member of resistant limestone 13 feet thick.

About $1\frac{1}{2}$ miles southwest of No Wood, where the creek emerges from a small canyon, the Embar is again found to contain prominent gypsum beds. A measurement showed about 42 feet of gypsum interbedded with red shale. This is the most southwesterly locality where gypsum beds of any economic importance were observed. A section of the Embar measured some 6 miles farther southwest, near the head of No Wood Creek and a little west of the center of T. 41 N., R. 89 W., is given in Plate IV (p. 144). No gypsum was found in that vicinity.

EAST OF THERMOPOLIS.

At the Red Spring anticline, which is about 9 miles east of Thermopolis, in T. 43 N., R. 94 W., the Chugwater and about 100 feet of the underlying Embar beds are exposed. Observations made by Mr. Lupton show that the beds are largely gray to brown calcareous shales, alternating with shaly gypsum, with a 16-foot bed of fairly pure gypsum near the top. The lowest exposures consist of the resistant limestone a little above the middle of the formation.

EAST SLOPE OF THE BIGHORN MOUNTAINS.

BILLY CREEK.

The exposures at Billy Creek, in T. 48 N., R. 83 W., include the lower 100 feet of the Embar formation, in which no valuable beds of gypsum were found. Owing to the talus good exposures are few, except along the steep slopes of the ravines. It is possible that the upper part of the formation is gypsum bearing.

MIDDLE FORK OF CRAZY WOMAN CREEK.

The hills on the north side of the valley of Middle Fork of Crazy Woman Creek, in T. 47 N., R. 83 W., contain the thickest gypsum deposits seen on the east slopes of the Bighorn Range. Section 11 in Plate V does not represent the entire thickness, and it is believed that the total is at least 150 feet. The gypsum consists largely of white layers free from mechanical sediment, with a few stained pink or dark by clay or other impurities. The texture is uniformly very fine. Between the massive beds of white gypsum are thin layers of gypsiferous red shale. In the midst of the gypsum is the purplish nodular chert member.

Partial analysis of gypsum from deposit near Middle Fork of Crazy Woman Creek.

[W. C. Wheeler, analyst.]

Potash (K_2O).....	None.
Lime (CaO).....	32. 81
Sulphur trioxide (SO_3).....	45. 42
Water driven off at $300^{\circ} C$	20. 40
Chlorine (Cl).....	None.
Silica (SiO_2).....	. 07
Manganese oxide (MnO).....	None.
Iron and alumina mixed (Al_2O_3 and Fe_2O_3).....	. 11

This analysis approaches closely that of pure gypsum. A slight excess of lime and a trace of carbon dioxide indicate the presence of a small amount of calcium carbonate.

BEAVER CREEK.

Exposures in the ravine near Beaver Creek, in T. 47 N., R. 83 W., show a large amount of gypsum both above and below the purplish chert member. Beds of limestone conglomerate are also abundant in the same vicinity at approximately the same horizon as the gypsum, but the two are not commonly associated in the same section.

Gypsum was also observed in the upper third of the Chugwater formation, in beds 25 to 40 feet thick. About 30 feet higher is oolitic gray limestone 25 feet thick.

SOUTH FORK OF CRAZY WOMAN CREEK.

The variable and discontinuous character of the gypsum beds is evident in the vicinity of South Fork of Crazy Woman Creek. The exposures along the main valley are not good except for the basal portion of the Embar, but it seems probable that gypsum is not present. Half a mile farther north, however, in T. 46 N., R. 83 W. (section 12, Pl. V), there is a great thickness of gypsum both above and below the purplish chert member.

NORTH FORK OF POWDER RIVER.

A section of the Embar was measured near the Webb ranch in the northwest corner of T. 45 N., R. 83 W. The formation consists of a mixture of red sandy shale and conglomeratic limestone, with thin beds of gypsum. The purplish chert member so characteristic of the Embar is present, but has been more or less removed by the erosion that produced the conglomerates. About 100 feet above the chert are beds of white and pink banded gypsum alternating with red shale. Their thickness is about 40 feet. It can not be stated whether these beds lie in the Embar or the Chugwater, because of the indefinite boundary between the two formations.

PHILLIPS RANCH.

The Phillips ranch is on Red Creek at the site of the McKenzie battlefield, in T. 44 N., R. 84 W. A short distance to the east the creek enters a deep, narrow canyon cut below the Tensleep sandstone along the axis of an anticlinal nose pitching southeast. The Embar formation in the structural cove to the west of the anticlinal nose, northwest of the Phillips ranch, consists of the usual red beds with conspicuous layers of conglomerate, on the surface of which the friable pebbles have been largely removed either by solution or wind erosion, which has left the vesicular, spongy, calcareous, cementing material with pockets large enough to be used for nesting places by birds. There is much gypsum along the base of the main mountain front west of the Phillips ranch and for several miles to the south. The deposits are found to be discontinuous when traced along the outcrop. The only persistent stratum in the upper part of the formation is the purplish-pink chert. The section of the gypsum beds (Section 13, Pl. V) can not be considered representative on account of their changeable character. The beds lie both beneath and above the purplish chert member. Those above are the thicker, being as much as 100 feet thick, inclusive of the intercalated thin layers of red shale. In the midst of the clean white gypsum beds is an irregular course of gray and white banded flint geodes, some of which are embedded in boulders of gypsum.

BARNUM AND VICINITY.

Exposures of the Embar between Beaver and Sheep creeks near Barnum, in T. 43 N., R. 84 W., contain little gypsum, but it is assumed that beds probably of considerable thickness exist under the surface along the base of the mountain and that they were once present on the slopes but have been removed by solution. The general distorted attitude of the red shales and thin limestone layers supports this belief. At the top of the hill is a conglomerate or breccia consisting of pebbles of reddish chert, limestone, and shale, cemented by a spongy, calcareous, sandy material. The rocks below consist of structureless red sandy clay marked at irregular intervals by thin layers of laminated limestone that are much distorted and broken by numerous small faults. These exposures rest on beds of red shale and limestone that show even lines of stratification, with little or no distortion.

In this same vicinity there is little gypsum in the lower part of the Chugwater formation, and that observed consists mostly of irregular veinlets in the red beds

CHARACTER OF THE GYPSUM.

The greater part of the gypsum in this region is white, but in many places it has a slightly pinkish or flesh tint caused by the presence of particles of red clay. The color varies from pure white to reddish or dark, according to the amount and kind of impurities. In places fragments of selenite, a transparent crystalline form of gypsum, are numerous along the outcrop of the gypsum beds, but they are of minor importance compared with the massive gypsum. In some beds considerable fine sand has been mixed with particles of gypsum, thus forming gypsite. This material, however, constitutes a very small proportion of the gypsum deposits of the region.

The analyses of the gypsum given above indicate that most of it contains very little calcium carbonate, or calcite. Pure gypsum contains 32.6 per cent of lime, 46.5 per cent of sulphur trioxide, and 20.9 per cent of water. The analyses show that the samples analyzed range from 32.72 to 34.20 per cent of lime. The percentage of lime in each analysis is greater than that of pure gypsum, and carbon dioxide is present in small amounts in each sample. It is noteworthy that the two samples from the Embar formation contain less carbon dioxide than those from the Chugwater formation. There is a possibility that a small amount of anhydrite is present and thus in part accounts for the excess of lime.

DEVELOPMENT.

The gypsum in the area described in this report is known to have been utilized at only two places, both near Greybull, on the west and south flanks of Sheep Mountain. Most of the gypsum is quarried in the upper part of the Chugwater formation about half a mile west of Stucco (section 1, Pl. V), a flag station on the Chicago, Burlington & Quincy Railroad. It is hauled by wagons to the railroad and shipped to Basin, about 18 miles distant. The gypsum is calcined and made into stucco blocks, which are used in building.

The mill at Basin is of small capacity, using about 200 tons of gypsum a month. In preparing the stucco blocks the raw gypsum is crushed, pulverized, and calcined. Care is taken in calcining not to overheat the pulverized gypsum, for if this is done it is said to be "dead burned," and the particles will not "set" or recrystallize. In calcining the gypsum is usually heated to about 177° C. (350° F.).

The selling price of the stucco blocks is small as compared with the price of lumber in this region. It is reported that blocks sufficient for the walls of a building 25 by 30 by 9 feet cost about \$200. Buildings made of this material are durable in a climate such as that of the Bighorn Basin. In a region where the rainfall is great the use of stucco blocks for buildings may not be advisable, but

where the rainfall is only from 5 to 12 inches annually they are sufficiently durable to last a lifetime and within a moderate distance from the mill they are less expensive than lumber.

Near the southeast end of Sheep Mountain, about 2 miles northeast of Greybull (section 2, Pl. V), a small amount of gypsum has been quarried and manufactured into stucco building blocks. It is hauled in wagons from the quarry a short distance to a small open kiln, where it is burned over a wood fire. After burning the gypsum is ground in a burrstone mill driven by a gasoline engine. The kiln is 8 by 11 by 5 feet and holds 12 to 15 wagonloads of material. About 500 blocks 8 by 9 by 24 inches are made from each burning. During three months in the spring and summer of 1915 2,500 blocks were made at this locality by the method above described. The blocks sell at 10 cents each at the kiln and 15 cents each delivered at Greybull.

Gypsum is not known to have been utilized elsewhere in the area described in this report, and it seems doubtful if the development of the gypsum industry in this general region will be rapid, owing to the large amount of good sandstone and limestone of building quality in the Bighorn Basin and adjacent parts of Wyoming.

As this report goes to the printer word comes that a mill is being installed at Stucco which will handle the gypsum quarried at that locality. The situation is so convenient to the railroad that the product will probably be shipped to all parts of the Bighorn Basin.



DEPARTMENT OF THE INTERIOR

FRANKLIN K. LANE, Secretary

UNITED STATES GEOLOGICAL SURVEY

GEORGE OTIS SMITH, Director

Bulletin 640—I

THE GOLD LOG MINE, TALLADEGA COUNTY
ALABAMA

BY

EDSON S. BASTIN

Contributions to economic geology, 1916, Part I
(Pages 159-161)

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THE GOLD LOG MINE, TALLADEGA COUNTY, ALABAMA.

By EDSON S. BASTIN.

In June, 1916, the writer made a brief inspection of the Gold Log mine. The visit was made in a few spare hours in an interval between other items of field work, with no intention of collecting data for publication, but as it was found afterward that no description of the mine has been published it appears desirable to record here the few observations made. A summary of existing knowledge regarding the gold deposits of Alabama, by H. D. McCaskey, was published in 1908,¹ but the Gold Log mine was not open for inspection at the time of Mr. McCaskey's visit to the region. The reader is referred to McCaskey's report for a review of the general geologic relations and descriptions of a number of similar gold deposits.

The writer is indebted to Mr. E. A. Thomas and Mr. W. B. Ladd for courtesies during his visit.

The mine is in Talladega County, Ala., about $7\frac{1}{2}$ miles south of Talladega, on the east side of the valley of Talladega Creek. It is operated by the Gold Log Mining Co., E. A. Thomas, president and manager. According to Mr. Thomas, the mine was formerly known as the Story mine and had been operated intermittently for perhaps 70 years before it was taken over by the present owners in June, 1915.

The rocks in the vicinity of the mine are assigned to the Talladega slate, which is regarded as of Lower Cambrian age. The wall rock of the vein is a gray, very fine-grained schist of slightly greenish cast, which strikes N. 60° – 65° E. and dips 35° – 40° SE. This schist is very finely foliated, and here and there its folia show prominent wavy cross-folding. At some places there are two sets of wavy cross folds, an early and a later set, which run nearly at right angles to each other, the earlier much smaller than the later. The microscope shows that this schist is composed of quartz, sericite, calcite (possibly introduced during mineralization), chlorite, and scattered irregular grains of magnetite, the minerals being here

¹ McCaskey, H. D., Notes on some gold deposits of Alabama: U. S. Geol. Survey Bull. 340, pp. 36–52, 1908.

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named in the order of their abundance. The flakes of sericite lie in subparallel positions. They are not evenly distributed but are aggregated into narrow bands, which are composed almost entirely of that mineral. It is these bands that give the rock its finely foliated structure. The other minerals are usually irregular in outline and show little tendency to elongation parallel to the foliation.

The vein has been exploited by a drift tunnel about 250 feet long, from which an incline follows the vein for about 320 feet. Most of the mining in recent years has been done below the tunnel, the greater part of the vein above the tunnel having been stoped out many years ago. The stopes range in width from 5 to 8 feet, the average being about 6 feet.

The ore consists of (1) irregularly interlocking white to light-gray quartz, white to pale-pink calcite, and very minor amounts of sulphides and free gold, and (2) schist partly replaced by some or all of these minerals. The principal sulphide noted was chalcopyrite, much of which shows peacock tarnishes. Enargite (?) also was noted, and magnetite was seen in one specimen. Free gold occurs locally in irregular masses in the quartz. The ore is usually massive and compact, showing no crustification or drusy cavities. It generally forms bands or lenses parallel with the folia of the schist. The contacts between ore and schist are as a rule extremely sharp, in places cutting across the folia of the schist, and sharp fragments of schist are here and there inclosed by ore. Elsewhere there are transitions, parallel to the trend of the folia of the schist, from typical sericite schist wall rock to a grayer rock less finely schistose, and from this rock to a typical assemblage of ore minerals. The microscope shows that the transition rock differs from the typical wall rock only in its larger content of quartz and calcite and in that the sericite bands are narrower and more widely spaced. It is believed to have been formed by the partial replacement of the sericite schist wall rock by calcite and quartz. Locally this replacement preceded the development of the lens-shaped bodies of massive ore, for in some places these cut sharply across the folia of the gray, partly altered schist. Abundant grains of pyrite, most of them less than 1 millimeter in diameter, were noted in some of the schist close to and in sharp contact with the massive ore, but pyrite is entirely absent from other schist similarly situated and was not noted in the gray, partly replaced schist that forms a transition product between ore and unaltered wall rock. As a rule, pyritization of the wall rock is local and inconspicuous.

In general, the relations of ore to wall rock appear to indicate a certain amount of replacement of the sericite schists by ore-forming

solutions penetrating along the folia of the schist in the early stages of the mineralization, followed by an actual prying apart and in places disruption of the folia in the later stages. Whether this disruption was a result of injection of the ore-bearing solutions under pressure or of the forces of crystal growth is uncertain.

The richer parts of the ore are typified by an exposure at the bottom of the incline, where a number of subparallel lenses of quartz, calcite, and metallic minerals together constitute about two-thirds of the 5-foot face. The individual lenses, which range from a few inches to a foot in width, are separated by sericite schist and by quartzose and calcitic schist formed by the partial replacement of the sericite schist. It is characteristic of the deposit that comparatively wide bodies of ore may decrease greatly in width or pinch out completely in very short distances parallel to the trend of the vein. For example, 6 feet along the strike of the vein from the 5-foot exposure just described, which was about two-thirds ore, practically all the vein quartz had pinched out, the entire face being sericite schist.

A mill at the mine is operated by water power obtained by damming Talladega Creek. The mill equipment consists of a jaw crusher, ten 750-pound stamps (2 batteries) dropping 75 to 80 times a minute; two 6-foot amalgamation plates, and tables covered with blankets. The capacity of the mill is about 25 tons in 24 hours. The value of the precious metals recovered is reported to average about \$4 to the ton of ore treated. Concentration is not attempted. The bullion recovered from the amalgam is shipped directly to the mint. The mint returns from 32 lots of bullion show that the ratio of gold to silver in the bullion ranges from 0.6 to 1 to 60 to 1; in most shipments the gold is in excess of 10 gold to 1 silver.



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**PLACER DEPOSITS OF THE MANHATTAN DISTRICT
NEVADA**

BY

HENRY G. FERGUSON

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PLACER DEPOSITS OF THE MANHATTAN DISTRICT, NEVADA.

By HENRY G. FERGUSON.

FIELD WORK AND ACKNOWLEDGMENTS.

During the field season of 1913 the writer spent four months in the study of the geology and ore deposits of the Manhattan district, Nev. The placer deposits offered problems of particular interest. Unfortunately in the present state of mining in the district these deposits could not be examined as thoroughly as might be desirable, and the present paper is offered as a description of an interesting type of deposit rather than a solution of the problems involved in the study of the Manhattan placers. The writer desires particularly to acknowledge his indebtedness to Mr. L. F. Clar, a veteran placer miner of the district, for much valuable information as well as for many helpful suggestions. The principal mining men of the district, among whom may be mentioned Messrs. C. Phillipps, S. E. Smith, T. S. Willetts, Percival Nash, and Omer Maris, all aided the writer in his work.

PREVIOUS WORK.

The geology of parts of the Toquima and Toyabe ranges was first made known by the geologists of the early surveys of the West. S. F. Emmons, of the King Survey, studied the Toyabe Range in some detail and also crossed the Toquima Range and visited Belmont, at that time the center of a prosperous mining district.¹ G. K. Gilbert, while a member of the Hayden Survey, also visited Belmont.² A geologic reconnaissance of the portion of the range between Belmont and the site of the present town of Manhattan was made by Spurr in 1899³ in the course of his explorations in central Nevada. Soon after the discovery of ore, but before the discovery of the placers, Manhattan was visited by W. H. Emmons and

¹ U. S. Geol. Expl. 40th Par. Rept., vol. 3, pp. 320-345, 393-405, 1870.

² U. S. Geog. and Geol. Surveys W. 100th Mer. Rept., vol. 3, pp. 36, 180, 245, 1875.

³ Spurr, J. E., Descriptive geology of Nevada south of the fortieth parallel and adjacent portions of California: U. S. Geol. Survey Bull. 208, pp. 90-93, 1903.

G. H. Garrey, and their report is the most important publication dealing with the geology and ore deposits of the district.¹ A description of conditions in the early days at Manhattan is given in a short paper by Claude T. Rice.² The first reference to the Manhattan placers occurs in an article by G. A. Packard,³ which contains an interesting description of early methods of working the surface placers. An article dealing directly with the placer mines was published by C. C. Jones in 1909.⁴ This paper gives a detailed description of the state of mining at that time. Other publications on the district deal exclusively with the lode deposits and the production of the lode mines.⁵

LOCATION AND TOPOGRAPHY.

The Toquima Range is situated in central Nevada (see fig. 18), between the Toyabe and Monitor ranges, and is one of the less prominent of the many narrow, isolated mountain ranges which are such notable features of the Great Basin topography. It trends in a northeasterly to northerly direction and extends from about latitude $38^{\circ} 25' N.$ to about $39^{\circ} 25' N.$ At Manhattan the range is broken by a low pass, and the portion of the range to the south is sometimes called the Smoky Mountains. The maximum elevation of this southern portion of the range is about 8,500 feet in the peaks west of Indian Spring. The main range is higher, and Jefferson Peak, east of Round Mountain, has an elevation of about 10,000 feet. The crest line is somewhat nearer the eastern than the western border of the range.

The range is bordered by desert valleys—Ralston Valley on the east and Big Smoky Valley on the west. On both sides, but particularly on the west, the boundary between rock in place and valley fill is irregular, in marked contrast to the sharp line of demarcation on the eastern front of the Toyabe Range. At its southern end a low, broad pass filled with desert wash separates the Toquima and San Antonio ranges.

¹ Garrey, G. H., and Emmons, W. H., Notes on the Manhattan district: U. S. Geol. Survey Bull. 303, pp. 84-93, 1907.

² Rice, C. T., The Manhattan mining district, Nev.: Eng. and Min. Jour., vol. 82, pp. 581-584, 1906.

³ Packard, G. A., Round Mountain camp, Nev.: Eng. and Min. Jour., vol. 83, pp. 150-151, 1907.

⁴ Jones, C. C., Notes on Manhattan placers, Nye County, Nev.: Eng. and Min. Jour. vol. 88, pp. 101-104, 1909.

⁵ Jenney, W. P., Geology of the Manhattan district, Nev.: Eng. and Min. Jour., vol. 88, pp. 82-83, 1909.

Evans, C. E., Manhattan: Am. Min. Cong. 12th Ann. Sess. Proc., pp. 398-400, 1909.
Toll, R. H., Present aspect of the Manhattan district, Nev.: Min. and Eng. World, vol. 35, pp. 589-640, 1911.

Quinn, P. J., Treatment at the Big Pine, Manhattan: Min. and Sci. Press, vol. 111, p. 320, 1915.

Nash, Percival, The mines and mills of Manhattan: Tonopah Miner, Aug. 15, 1915; abstract in Min. and Sci. Press, vol. 111, p. 523, 1915.

Irregular hills jut out into the valley in many places. Between the waste-filled portion of the valley and the foothills of the range there is in most places an irregular strip, at the greatest 1 mile in width, where the rock surface continues the gentle grade of the valley sides. This is well shown in the northwestern part of the Manhattan area. The border of the range is more clearly defined on the side of Ralston Valley than on the side of Smoky Valley, and the hills facing Ralston Valley show bold escarpments, though here, as on the west side of the range, there is a border of rock plain between the hills and valley. South of Belmont a range of low hills extends southeast, connecting the Toquima Range with its eastern neighbor, the Monitor Range.

On the east flanks of the range the mountain topography is distinctly youthful, and the streams flow through steep canyons to the rock-cut bench which borders the valley. The hills are everywhere steep and rugged. On the west side, however, a more mature stage of erosion is reached, the stream valleys

are flaring near their mouths and are graded in their lower courses, irregular smooth hills of more resistant rock show the effect of differential erosion, and it is only near the center of the range that there are steep canyons and rugged hills. A narrow belt along the crest of the range, above 9,000 feet elevation, shows a marked contrast to the rough topography below. Here there is a belt of rolling upland, not flat enough to be called a peneplain, but an area whose gentle relief indicates that it is a relic of very mature topography from a previous topographic cycle.

The Manhattan district has an arid desert climate, which is mitigated, however, by the presence of the mountains to the east. During the winter there is a considerable snowfall, and snow stays on the higher ridges for several months. In the summer short, heavy

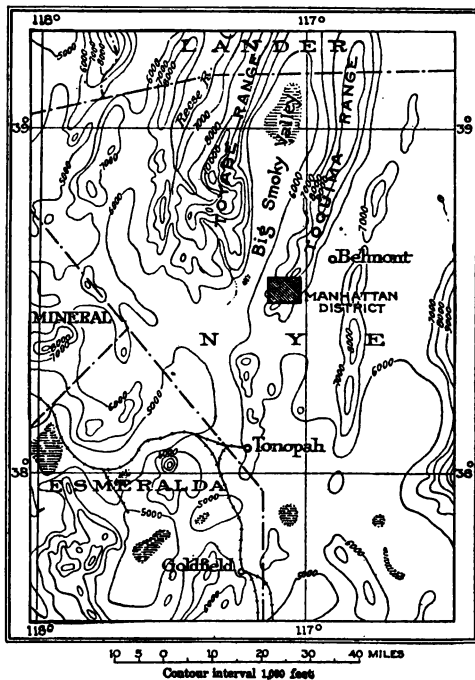


FIGURE 18.—Map of part of central Nevada, showing the location of the Manhattan district.

rains break the monotony of cloudless skies and at times give rise to destructive floods.

The Toyabe Range has a sufficient elevation to retain small patches of snow from year to year, and consequently permanent streams are fairly numerous, but in the Toquima Range streams are less common, although numerous small springs exist in the uplands. Northward from the south end of the range, as far as Shoshone Creek, a short distance north of Round Mountain, no stream carries sufficient surface water to allow it to overcome evaporation and reach the valley. In several of the dry canyons, such as Timber Hill Gulch and Manhattan Gulch, there is, however, a considerable underground flow beneath the gravels. In Manhattan Gulch this underground flow is estimated at about 50,000 gallons a day and is sufficient for placer-mining work.

The belt facing Big Smoky Valley supports only the usual desert bush growth. In the hills to the east, however, between elevations of 7,000 and 9,000 feet, there is a rather sparse growth of pine and juniper. Above the timber line only small clumps of mountain mahogany can exist. Shoshone and Jefferson creeks, before they are lost in the desert, are bordered by a thick growth of willows, which give a pleasant contrast to the parched surroundings. To the west the scanty desert vegetation becomes more and more sparse until the bare sun-baked playas of the central part of Smoky Valley are reached.

The nearest railroad point is Tonopah, 32 miles by road from Manhattan, with which it is connected by a daily automobile stage. Automobile stages connect Manhattan with Round Mountain and Belmont. In the early days of the Manhattan boom a railroad to connect Tonopah with Manhattan, Round Mountain, and Austin was surveyed but never constructed.

HISTORY AND PRODUCTION.

The discovery of the ore deposits of the present Manhattan district dates from April, 1905, when "specimen ore" was discovered by John C. Humphrey on April Fool Hill only about a hundred feet from the Belmont road. An old mine about 4 miles south of the present town of Manhattan had, however, been worked in the late sixties.

The discoveries of rich surface ore with plentiful free gold were made within a few hundred feet of the road leading west from the old camp of Belmont. It seems strange that such ore should have passed unnoticed for 40 years. The older prospectors, however, were looking for wide quartz veins of the type of those at Belmont, and took no notice of the inconspicuous lodes which characterize the later-discovered deposits.

In August following the discovery there was a rush of prospectors, but the camp was later deserted, though it filled up again the following winter. In March, 1906, there were 3,000 people in Manhattan and the immediate vicinity.^a At about the time of the discovery of gold on April Fool Hill silver-bearing lead ore was found near the site of the now abandoned camp of Palo Alto.

During 1906 the district was in a state of great excitement, rich discoveries were constantly being reported, and people streamed in from all over the country. Besides Manhattan there were three other towns—East Manhattan, Central, and Palo Alto. To-day only tin cans mark the site of Palo Alto, and two or three shacks are all that is left of Central and East Manhattan. The winter of 1907–8 was marked by depression following the deflation of the boom, but the hard times, which led to temporary cessation of quartz mining, turned the attention of the miners to the placers of Manhattan Gulch and the possibilities of drift mining. Placer mining had been begun in 1906 with the dry washing of rich surface material on the Little Grey and Indian Camp claims, but the gulch was not prospected until the following year. The placers gave new life to the camp, for the gravel was extraordinarily rich in places, and mining comparatively cheap. The richest placer ground was exhausted by the end of 1912, and since then the placer production has decreased. Probably two or three years more will see the end of the more important placer operations.

The accompanying table tells very clearly the story of the rise and decline of the lode and placer mines of the Manhattan district. The figures given for placer production are undoubtedly too low, for "high grading" is known to have been prevalent, and lessees sometimes conceal their returns to avoid payment of royalty and bullion tax.

Gold and silver production of the Manhattan district, Nev.^b

Year.	Lode mines.						
	Producing mines.	Ore (tons).	Gold.		Silver.		Total value.
			Fine ounces.	Value.	Fine ounces.	Value.	
1906.....	5	677	3,874	\$80,074	5,697	\$3,817	\$83,891
1907.....	5						33,622
1908.....	9	10,789	12,002	248,075	6,075	3,228	251,303
1909.....	13	4,198	3,710	76,601	1,937	907	77,598
1910.....	31	14,671	12,722	262,958	6,113	3,301	266,259
1911.....		13,945	20,255	418,683	8,489	4,499	423,182
1912.....	20	21,064	15,608	322,534	6,987	4,297	326,831
1913.....	31	46,228	13,733	283,854	4,516	2,728	286,582
1914.....	24	39,746	6,918	143,002	2,548	1,409	144,411
							1,893,679

^a Emmons, W. H., and Garrey, G. H., Notes on the Manhattan district: U. S. Geol. Survey Bull. 303, p. 85, 1907.

^b From U. S. Geol. Survey Mineral Resources.

Gold and silver production of the Manhattan district, Nev.—Continued.

Year.	Placer mines.						Total value for lode and placer mines.
	Producing mines.	Gold.		Silver.		Total value.	
		Fine ounces.	Value.	Fine ounces.	Value.		
1906.....							\$83, 891
1907.....							33, 622
1908.....	7					\$16, 371	267, 674
1909.....	16	2, 266	\$46, 847	965	\$497	^a 67, 344	^a 144, 942
1910.....	29	4, 772	98, 644	1, 958	1, 077	98, 701	365, 960
1911.....	26	6, 582	136, 052	2, 737	1, 451	137, 503	560, 685
1912.....	17	8, 152	168, 512	3, 232	1, 987	170, 499	497, 330
1913.....	34	8, 061	166, 622	3, 104	1, 875	168, 497	455, 079
1914.....	31	6, 307	130, 370	2, 323	1, 247	131, 617	276, 028
						791, 532	2, 685, 211

^a U. S. Geol. Survey Mineral Resources, 1910, p. 526, 1911, states that placer production as given in the report for 1909 is \$20,000 too low. This amount is therefore added to the totals, other figures remaining as given in Mineral Resources for 1909.

AREAL GEOLOGY.**ROCK FORMATIONS.**

The rocks of the Manhattan district include Paleozoic sediments, intrusive granitic rocks of Mesozoic age, and Tertiary lavas and intrusives, with associated sediments. (See Pl. VI.) The older sediments are much metamorphosed and closely folded. Their general structure is that of an anticline whose axis strikes a few degrees west of north and pitches gently to the west. In the Manhattan district a threefold division of these sediments has been made. The first division consists dominantly of brown micaceous schist but also contains much quartzite and impure gray sandstone and a few small beds of crystalline limestone. It extends from Wolfe Tone Point southeast by east in a gradually widening belt, reaching a width of a little over a mile on the east border of the area. This division is followed by a series composed chiefly of dark limestone and black jasper but containing also much black and gray slate. This series occupies an irregular belt from half a mile to 2 miles in width surrounding the lower series. In places some of the beds are undoubtedly repeated by faulting.

The base of the highest sedimentary series is marked by lenticular beds of white quartzite, with which are associated a few feet of black slates. These slates contain numerous graptolites of Ordovician age. Above the quartzite horizon the upper series consists dominantly of schistose chloritic slates, with a few beds of brown slaty limestone and numerous small lenses of hard darker slate. These occur above the limestone series and occupy the extreme southwest part of the area. Here the ridges are in general parallel to the strike and more continuous than those of the limestone series.



Base from geology by H. G. Ferguson
map of Mar

LEGEND SEDIMENTARY ROCKS

Recent		Desert wash	QUATERNARY
		Stream gravels <i>In part concealing Pleistocene gravels</i>	
Pleistocene (?)		Older gravels	
		Tuffaceous sandstone and shales	TERTIARY
		Breccia beneath oldest lavas	
		Chiefly slates and schist with quartzite near the base	PROBABLY ORDOVICIAN
		Dark limestone and black jasper with slate at the base	PROBABLY ORDOVICIAN
Upper Cambrian		Mica schist, impure limestone, and quartzite; lenses of crystalline limestone near the top	CAMBRIAN
	IGNEOUS ROCKS		
		Intrusive andesite porphyry	
		Upper tuffaceous rhyolite	TERTIARY
		Porphyritic rhyolite	
		Lower rhyolitic tuff and rhyolite <i>Numerous dikes and irregular masses of intrusive rhyolite intruded into this formation have been omitted from this map. Most of these occupy the higher ground in the western part of the area.</i>	
		Granite <i>Numerous small dikes of granite and aplite are not mapped.</i>	CRETACEOUS (?)

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The lower limestone is in places silicified and extremely resistant and the quartzite bands differ widely in thickness. Hence the topography of the limestone area is extremely irregular, and isolated hills such as Black Mammoth Hill, Mount Moriah, and Palo Alto Hill stand without apparent relation to one another.

The rocks of the sedimentary formations all contribute to the Manhattan placers. Owing to their greater resistance quartzite pebbles are present in the lower gravels in far greater proportion than the other sediments. Large quartzite boulders are common in nearly all the placers. The dark silicified limestone in some places occurs as large boulders, but these are more rare. Pebbles of jasper and calcareous slate are numerous, but these rocks are too brittle to form large boulders. Slate and schist occur chiefly as small flat pebbles, particularly in the fine gravels.

Granite is exposed over only a very small part of the area, but the isolated patches along the southern border are outliers of a mass which occupies large areas to the south, east, and north of the Manhattan district. Besides the granite there are many small alaskitic dikes which traverse the country rock, particularly in the southwestern part of the district. Granite is present only in a very small patch in the Manhattan Gulch drainage area. Granite pebbles are nevertheless not uncommon. It is probable that many of these pebbles were originally present as inclusions in the lower rhyolite, or it may be that the valley once drained a part of the granite area to the east.

Tertiary formations, chiefly lavas, occupy the northern and northwestern portions of the area. Between Big Smoky Valley and Black Mammoth Hill the contact with the sediments is sharp and is probably formed by a fault. East of Mustang Hill, however, a belt of breccia lies between the sediments and the lower member of the volcanic series. This is composed of angular fragments of the older sedimentary rocks and represents talus slopes of the prevolcanic period. In places it is well cemented but in the placer gravels is not distinguishable from the sediments from which it is derived. The earliest member of the volcanic series is a white rhyolite tuff containing numerous fragments of the older rocks. A few small flows of dark glassy rhyolite occur in the tuff series. The tuffs are easily eroded and occupy a broad lowland belt extending from the east border of the area to the northwest corner. The rock is too soft to be abundant in the placer gravels but forms a part of the unsorted wash close to the surface. Along a portion of the south border of the tuff area there are irregular intrusions of a fine-grained rhyolite. This rock is far more resistant than the tuff and finds topographic expression in the irregular hills north of Black Mammoth Hill and the Round Mountain road.

The next member of the series is a massive flow of porphyritic rhyolite, which forms the prominent cliffs of the hills south of Bald Mountain. It breaks into large blocks on weathering and has furnished a large proportion of the coarser material in the placer gravels. Above the porphyritic rhyolite are tuffs and sandstones of the same mineral composition which are only distinguishable from the lava where weathering has accentuated the bedding planes. Rhyolite and rhyolite-like tuff together have a maximum thickness of about 800 feet in the northeastern part of the area.

Above this series comes about 400 feet of thin-bedded quartzose sandstones and fine-grained shales, composed of material derived from the underlying rhyolite. These rocks, under the influence of weathering, split readily into thin plates, and the area which they occupy is marked for the most part by smooth slopes. The sandstones outcrop in an irregular belt above the steep slopes of the rhyolite porphyry near the summits of Bald Mountain and Buckeye Hill. As the rock is comparatively friable sandstone pebbles are not common in the placer gravels.

The next rock in the lava series is a white tuffaceous rhyolite, which closely resembles the lowest member of the series except that the foreign inclusions are much smaller and less conspicuous. This rock crowns Buckeye Hill and Bald Mountain and reaches its greatest development in the hills just to the east. It has a maximum thickness of 600 feet, though a part is lost by erosion. It is comparatively soft, and the pebbles are worn away before they enter the placer gravels of Manhattan Gulch.

An irregular mass of rather coarse grained andesite porphyry forms a line of sharp-pointed hills extending eastward from Slaughterhouse Gulch. This rock is intrusive into the lower tuffaceous rhyolite and porphyritic rhyolite and has probably entered along a fault plane, for the tuffaceous rhyolite is repeated on the north. Small dikes and masses of the same rock also occur on the flanks of Buckeye Hill and Bald Mountain, where they are intruded into the sandstone. These dikes were not found in the upper tuffaceous rhyolite, and as that rock carries no andesite pebbles the andesite porphyry is probably younger. It is very tough and resistant and pebbles are numerous in the placer deposits. The andesite porphyry occurs only in the northern portion of the area, so pebbles of this rock in the gravels south of the present gulch serve to distinguish the older stream gravels from the more recent wash from the hills to the south.

A small area of a more recent lava, probably dacitic in composition, overlies the sandstone in the northwestern part of the district but does not come within the Manhattan Gulch drainage area.

LODE DEPOSITS.

The lode deposits of the Toquima Range belong to two different periods. The intrusion of the quartz monzonite batholith and its accompanying silicic dikes was followed by a period of ore deposition, of which the most important examples are the tungsten deposits of Round Mountain and Spanish Springs and the silver-lead veins of Belmont. In the Manhattan district, however, no valuable deposits belong to this period. The Nemo mine, near Central, has been developed along small quartz veins containing galena, tetrahedrite, and chalcopyrite, and small silver-lead veins have been prospected near the abandoned camp of Palo Alto. A silver mine was worked in the sixties near the head of Old Manhattan Gulch, south of the area mapped.

All the gold and silver production has been derived from deposits of Tertiary age. The deposits are veins in the lava and schists and veins and replacement deposits in the crystalline limestone bands of the older schist series. In part, at least, the deposits are older than the andesite porphyry, for the veins cut that rock.

The veins in the lavas have been prospected chiefly near Bald Mountain but have so far yielded little return. The ore consists of minute veins of iron-stained quartz, with minor amounts of calcite, which is in places replaced by quartz, barite, and rarely fluorite. Pyrite has been present but is now completely oxidized to limonite, though for the most part it retains the original shape of the pyrite crystal. Here and there minute specks of free gold can be seen on the surface of the grains of altered pyrite. None of these deposits has as yet reached the productive stage.

The veins in the Cambrian schist have been the largest producers in the district. These veins are confined to Gold Hill and the immediate vicinity. For the most part the lodes consist of numerous closely spaced minute quartz stringers, which cut the schist in all directions, following, however, a definite zone of mineralization. Near the surface these carry coarse gold in crystalline aggregates, almost certainly the result of secondary deposition. The little veins break readily from the schist country rock, so that it is possible to effect a preliminary concentration by screening. Barite is present in small amounts in the gangue and a little calcite was noted, but fluorite seems to be entirely absent. The mines working this type of deposit are the Big Four, Big Pine, Stray Dog, Jumping Jack, Union No. 9, Riley Fraction, and Little Grey, all within half a mile from the top of Gold Hill and within 3,000 feet of Manhattan Gulch. This type of deposit has undoubtedly furnished most of the gold to the placers of the gulch.

Narrow belts of limestone occur near the top of the lower schist series and have proved to be the locus of many ore deposits, particularly on Mustang, April Fool, and Litigation hills. Here the ore occurs both in narrow fissures and in replacement deposits extending out into the limestone from small mineralized fault fissures. In most of the deposits the gold is free and occurs in finely crystalline quartz. Near the deposits the limestone is in many places altered to very coarsely crystalline white calcite. Large crystals of fluorite are characteristic of the gangue. On the same belt of crystalline limestone, but differing from the other deposits, is the White Cap mine, at the head of Consolidated Gulch, about a mile east of town. Here the ore bodies consist of large replacement deposits in the limestone. In contrast to the other deposits free gold is lacking, and stibnite and realgar are present in considerable amounts. The gangue consists of hard, dense quartz and very coarsely crystalline white calcite.

The rocks of the upper sedimentary series have not proved productive, though small veinlets of quartz carrying free gold have been prospected on Black Mammoth and Georgey hills on the north side of the gulch.

In general the veins of the district have been characterized by the occurrence of rich "specimen ore" locally at the surface, followed by a sharp decline in tenor at moderate depth. Part of the gold has apparently been taken into solution and redeposited a short distance below the outcrop. Erosion has been more rapid than the process of enrichment, and a part of the gold of the enriched zone has been carried down into the gulch.

DEVELOPMENT OF THE PRESENT TOPOGRAPHY.

The period of volcanic activity ended sooner in the region occupied by the present Toquima Range than elsewhere in the Great Basin country, for Pleistocene lavas are probably lacking. The lava-covered region was eroded until an extremely mature topography, approaching the peneplain stage, was reached. This topography was fairly general over this portion of the Great Basin region, for Ball¹ mentions the existence of similar old topographic forms on the Kawich, Belted, Amargosa, and Panamint ranges to the south, and Meinzer² has found a similar mature topography on the Toyabe Range. As this older erosion surface extends over so large an area, it follows that the present mountain ranges must be of later date. Ball considers this mature land surface to be of late Pliocene age, as it is

¹ Ball, S. H., A geologic reconnaissance in southwestern Nevada and eastern California: U. S. Geol. Survey Bull. 308, pp. 16-17, 99, 119, 161, 202, 1907.

² Meinzer, O. E., Ground water in Big Smoky Valley, Nev.: U. S. Geol. Survey Water-Supply Paper 375, p. 90, 1915.

later than the "later rhyolite" of early Pliocene age and older than the later tuffs and older alluvium which mark the transition from Pliocene to Pleistocene. Hence the major part at least of the mountain-building movements must have been confined to the early Pleistocene, for at the period marked by the Pleistocene lakes a topography approaching the present had been attained.

A review of the controversy regarding Great Basin structure would be out of place in this paper. The writer believes that the Toyabe and Toquima ranges represent tilted fault blocks, the fault in each range being on the east side.

It would seem to be impossible for anyone looking at the eastern front of the Toyabe Range from the lower slope of the Toquima, across Big Smoky Valley, to doubt the presence of a fault scarp. Long spurs, which slope gently down from the crest, are sharply truncated and present steep triangular faces toward the valley. The great fault scarp is so fresh that, although the streams have cut canyons close to the valley, wide interstream areas are practically undissected. The streams themselves show the reversal of normal effects of erosion. The headwaters and upper reaches are wide and open, whereas at the mouths the streams flow through steep, narrow canyons. The front of the range follows a broadly sinuous rather than straight line, but in the 30 miles shown on the topographic map it varies less than a mile to either side of a north and south line. Faulting has continued until recent times, for Meinzer¹ reports that fault scarps cut the alluvial fans at the canyon mouths.

In the Toquima Range, however, there is an entirely different condition of affairs. On the west side the streams enter essentially at grade, and beneath the valley wash the rock shelf which borders the mountains deepens gradually westward. Moreover, the boundary between gravel and rock outcrop is irregular, and the gravel at the edges is clearly only a thin veneer resting on a planed-off rock surface. This rock bench ends rather abruptly on the east, in irregular ridges, the outliers of the main mountain mass. There is a notable lack of gradation between the gently sloping rock bench and the upland. The belt of irregular uplands shows generally youthful topography but approaching maturity. The larger stream valleys are in part filled with gravel in their lower courses, but the streams are still eroding their headwaters and eating back into the remnant of old topography which occupies the crest of the range. Terracing indicates more recent changes of level.

On the east side of the range there is a marked difference in the topography. Meadow Creek rises in the mature upland south of Mount Jefferson and flows southeast through a gradually narrowing valley until at its mouth it is inclosed in vertical walls of rhyo-

¹ Meinzer, O. E., op. cit., p. 91.

litic agglomerate. There is no flaring of the valley at the mouth, and the stream enters Monitor Valley over a broad, flat alluvial fan directly from the canyon. No difference in hardness of the rocks can explain this abnormality, for in its upper reaches the country rock is a dense rhyolite, whereas in the canyon it is a coarse rhyolitic agglomerate, which should be the more easily eroded of the two. East Manhattan Gulch also trends southeasterly from the low divide east of Manhattan to Ralston Valley, and, though without permanent surface flow, it exhibits the same inversion of normal conditions which characterizes Meadow Creek valley. Near East Manhattan there is a wide gravel-filled valley cut for the most part in the lower tuff and the underlying breccia but in part in the harder quartzite and schist of the older sediments. To the southeast the valley sides steepen until for a mile above its mouth the gulch is a deep, narrow canyon with walls of schist and jaspery limestone. These conditions in the two gorges probably indicate that the east front of the Toquima Range was formed by faulting, for if the large valley to the east were the work of erosion the tributary streams would of necessity be best graded near their mouths and would there closely approach the grade of the trunk stream that occupies the main valley. Other evidence of faulting is not as clear as in the Toyabe Range. The east front, particularly near Belmont, does not present a simple scarp, although north of the town a continuous line of rhyolite cliffs faces the valley. Movement along the fault plane bounding the Toquima Range probably ceased long before faulting had ended on the Toyabe, and wherever rocks of varying degrees of resistance were present, as the granites and Paleozoic sediments of Belmont, long-continued erosion has destroyed the fault scarp. Where the range is composed of fairly homogeneous rhyolite, as to the north of Belmont, the fault scarp has retreated fairly regularly, leaving a rock bench between it and the wash-filled valley.

The minor range connecting the Toquima and Toyabe ranges is probably the result of oblique faulting.

It is probable that a topography which in its main outlines at least resembled the present had been developed in early Pleistocene time, primarily through the agency of block faulting. During a period of less arid climate than the present, presumably contemporaneous with the Pleistocene Lakes Bonneville and Lahontan, two salt lakes, named Tonopah and Toyabe by Meinzer,¹ existed in Big Smoky Valley. Lake Tonopah was in the southern part of the valley, west of Tonopah, between Millers and Blair Junction, and Lake Toyabe occupied a portion of Big Smoky Valley between the Toquima and Toyabe

¹ Meinzer, O. E., *op. cit.*, p. 90.

ranges. The southern limit of the lake was in latitude $38^{\circ} 45' N.$, a few miles north of Round Mountain, and it extended north to about latitude $39^{\circ} 18' N.$ Its length was about 40 miles, its maximum width 9 miles, and its depth 170 feet. Its position to-day is marked by the playa between Round Mountain and Milletts. According to Meiner¹ the old shore lines are still horizontal.

MANHATTAN GULCH.

DRAINAGE AREA.

The drainage area of Manhattan Gulch extends eastward from Big Smoky Valley to a point on the Belmont road three-fourths of a mile west of East Manhattan, a distance of about 6 miles. The divide forming the eastern boundary follows a nearly straight line north to Bald Mountain and south to Summit Hill. The divide on the northern side is about 2 miles north of the gulch in the extreme eastern part, but it turns sharply southward, crosses the belt of soft rhyolite tuff at the head of Black Mammoth Gulch, and for the greater part of the distance parallels the course of Manhattan Gulch at a distance of a half to three-quarters of a mile to the north. On the southern side Timber Hill, a high ridge composed of metamorphic slates and a little granite, forms the divide, which follows a nearly straight westerly course about 2 miles south of Manhattan Gulch. The drainage area is thus notably asymmetric, for over the greater part of the area the divide is much nearer the gulch on the northern than on the southern side. It seems probable that the diversion of a part of the former drainage westward to Big Smoky Valley, has been effected through the gradual disintegration of the belt of soft rhyolite tuff which crosses the head of Black Mammoth Gulch and the transportation of the material by occasional floods, rather than through normal stream erosion.

On the north side Manhattan Gulch receives two important tributaries, Slaughterhouse Gulch, which enters near the north end, and Black Mammoth Gulch, which joins the main valley between Black Mammoth and Mustang hills. Both gulches drain territory covered by volcanic rocks, and in both the prospect shafts show a deep filling of gravel. On the south side several gulches, of which the most important are Consolidated, Dublin, Big Pine, Auction, Old Manhattan, and an unnamed gulch in the extreme west, flow into the main valley. These gulches for the most part have a northwesterly course, roughly accordant with the strike of the sediments in which they have cut their valleys. None of them contain anything like the gravel de-

¹ Op. cit., p. 91.

posits of the northern tributaries, although all except the two westernmost are filled with gravel for a short distance back from their mouths. This difference is believed to be due not to any tilting northward but to the fact that the southward-flowing streams, in the period when erosion was at its height, easily cut their valleys down to grade across the belt of soft rhyolitic tuff, whereas those on the south, which flowed across rocks of more equal resistance, maintained a generally more even grade throughout.

There is no direct evidence of a change in either direction in the position of the main divide between Manhattan Gulch and the eastward-trending East Manhattan Gulch, though East Manhattan Gulch shows a topography directly the opposite of Manhattan Gulch. At its headwaters there is a low-lying area containing a few feet of waterworn gravel. Eastward toward Ralston Valley the stream flows on bedrock through a narrow canyon cut in metamorphic rocks. The stream has clearly the advantage in slope over Manhattan Gulch and is eating headward into the gravel area west of East Manhattan.

It is quite probable that the valley of the Pleistocene stream from which the present deep gravels are derived headed much farther to the east or southeast and lost its headwaters through capture. The only topographic evidence in favor of this change is the broad valley of Big Pine Gulch, which extends from Manhattan to Pipe Spring, in the southeast corner of the area shown on the Manhattan map. At a point about $1\frac{1}{2}$ miles southeast of Manhattan and a mile west of Pipe Spring there is a low divide east of which the drainage goes eastward. At Pipe Spring the course of the stream changes sharply and turns southward through a steep canyon of granite and metamorphic sediments. South of the Belmont road is another low divide between the drainage of Manhattan and East Manhattan gulches, but there is nothing in the present topography to indicate stream capture. The lower gravels show an excess of pebbles derived from the sediments over those from the rhyolites, a relation which is reversed nearer the surface, and this change in the character of the gravels, together with the presence of well-rounded granite pebbles in the lower gravels, lends probability to the hypothesis that the stream formerly had a greater extension in the region covered by the granite and older sediments.

The course of Manhattan Gulch is an inheritance from an earlier physiographic cycle, for it is completely independent of the structure of the rocks across which it flows. The easily eroded rhyolitic tuff forms a lowland belt extending from east to northwest across the area but is nowhere occupied by a stream valley, whereas Manhattan Gulch over the greater part of its course is inclosed in walls of metamorphic sediments whose strike is transverse to the valley.

BEDROCK CONFIGURATION.

The gulch shows traces of several different stages of erosion. The earliest stage is not brought out in the topography but is shown in the patches of older gravels here and there along the valley sides at elevations whose greatest height is 70 feet above the present stream course. The later stages are preserved in the buried bedrock topography of the gulch itself.

The deepest channel on bedrock is at depths of 40 to more than 100 feet below the present surface of the gulch. Several fragmentary benches at higher elevations represent stages in the erosion of the canyon, but the outer walls are everywhere steep. The old Wolfe Tone shaft, for instance, reaches bedrock at a depth of 70 feet not over 50 feet from the rock outcrops on the end of Wolfe Tone Point, and at "The Narrows" below the Happy Day claim the slope to the deep channel appears to be even steeper. The rock benches, as far as could be observed, are not sharply defined but grade rather gently into one another and into the deep channel and are covered with a constant mantle of gravel.

The average grade of the present surface of the gulch, between the town of Manhattan and the Japan claim, is $3\frac{1}{2}$ per cent, but the grade is slightly steeper in the eastern and flatter in the western part. The average grade of the bedrock is approximately the same, though the westernmost shafts are the deepest. It is, however, far less regular than the grade of the surface and alternates between level graded stretches, where the softer rocks have been worn down, and rapids, where the stream crossed the more resistant beds of the sedimentary series.

The deep channel has been explored for practically its entire length, but in the present condition of mining it is difficult to obtain sufficient data to reconstruct its course. It meanders about the valley bottom and at several points splits into two or more divisions, leaving small "islands," a few feet high, between the deep channels. The course as shown on the map has been compiled from data obtained from the open shafts, supplemented by maps furnished by Mr. Clar.

There is a depth of about 30 feet to bedrock under the town of Manhattan, but the depth increases to 60 feet in the shaft at the west end of the Dexter No. 14 claim, a short distance below the town. Probably the quartzite beds in the lower schists here formed a dam, for above this place the bedrock channel is fairly flat, at least as far as the mouth of Consolidated Gulch, where the depth is between 50 and 60 feet, showing a drop in bedrock of 95 feet, as compared to a difference of elevation of 125 feet on the surface, in a distance of about 2,500 feet.

Between the Dexter No. 14 claim and Wolfe Tone Point the grade of bedrock is only slightly steeper than the surface, since the shaft opposite Wolfe Tone Point has a depth of 72 feet. Along this stretch the deep channel follows the south wall of the canyon.

Between Wolfe Tone and African points there seem to be two, perhaps three channels of about equal depth, which unite again on the north side of the valley at African Point. Possibly the variation of the channel is due to the displacement of the stream by the delta of Auction Gulch. This tributary seems to have entered the stream at a steep grade and must therefore have deposited much of its load near its mouth. The grade of bedrock is only slightly less than that of the surface, for the upper shafts have depths of 70 feet or more and that of the African claim, near the junction of the channels, is 65 feet in depth. Below African Point there is a long stretch in which the bedrock is slightly flatter than the surface, for the depth is about 60 feet on the Searchlight, 50 feet at the Central City, and about 45 feet from the Pedro to the Last Chance claim. The channel swings from the north side of the canyon at African Point to the south side directly north of Mount Moriah and again to the north at the Last Chance. This graded stretch appears to be caused by the extension under the stream of the quartzite bed which forms the crest of Georgey Hill.

Below Georgey Hill there is a comparatively rapid fall, the canyon narrows, and for a short distance the benches are lost. The next known depth to the deep channel is 60 feet on the Arlington No. 3, a drop of 15 feet below the surface grade. The greater part of the fall is believed to be on the Fairview and the lower end of the Edith claims. Below the Arlington No. 3 the grade of bedrock is steeper than that of the surface, the depth being 78 feet on the Bright August, 88 feet in the western part of the Jumbo No. 2, 93 feet on the western edge of the Lucky Fraction, and 105 feet on the China. Between the Polaris and the Bright August well-defined bench gravels have been worked, but on the lower end of the Happy Day the canyon again narrows and the benches are lost. At the upper end of the Happy Day claim the depth to bedrock is 70 feet; at the lower end of the same claim it is 90 feet; and at "the narrows," just below, a depth of 98 feet is reached. The bedrock on the Happy Day claim is said to be very uneven and to show numerous "jump-offs." Below the narrows, on the China claim, the canyon is wider and the benches come in again.

Below the China the gulch turns sharply to the north and continues in this direction for about 5,000 feet, where it bends to the northwest. Along this stretch the surface expression of the gulch begins to be lost under the desert wash of Smoky Valley. The bedrock canyon seems to continue, however, though the grade is much flatter,

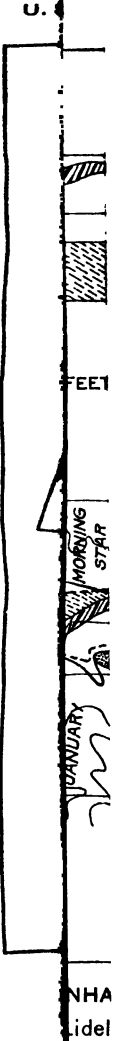
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for the Japan shaft, 400 feet to the north, is 90 feet deep, and the farthest shaft, on the Hillsdale No. 1 claim, 8,000 feet beyond the China, is said to have a depth of 70 feet.¹

In the accompanying map (Pl. VII) no attempt has been made to show the true width of the deep channel, for sufficient data are not available. In general it is widest in the graded stretches and narrows toward the rapids. In the long graded stretch east of the Last Chance it reaches a maximum width in places of about 100 feet. In the west end of the Bright August, just above the narrow portion of the Happy Day, the width is only 10 feet. Below, on the Japan claim, it is said to be 50 feet wide.

GRAVEL DEPOSITS.

Gold has been mined from gravel of three types: The old gravels, still existing in small patches along the sides of the gulch above the present stream level; the deep gravels of the gulch; and the surface wash and shallow stream gravels in the immediate vicinity of the lode outcrops.

OLDER GRAVELS.

As the stream is so entirely independent of structure it has probably held its course from some time previous to the rejuvenation of erosion which initiated the present physiographic cycle. Jefferson Creek, the next prominent stream to the north, shows its different stages of erosion by a series of well-defined terraces. In Manhattan Gulch the early gravels are preserved only in small patches here and there along the sides of the present gulch at elevations of 20 to 70 feet above the present valley floor. These areas of older gravels are in large part buried under more recent wash and probably cover a somewhat larger area than is indicated on the map. They are distinguishable from the more recent wash by reason of the greater rounding of their pebbles and the presence of pebbles of andesite porphyry, which must have been derived from the region of Slaughterhouse Gulch.

This gravel is coarse. The majority of the pebbles are rounded to subangular and about 4 to 8 inches in greatest diameter, though there are a few boulders of larger size. Fine clay and sandy material serves as a cement, but only in one place was a distinct bed of sand or fine gravel seen. The best exposures were found in the upper part of the gulch, particularly in the north face of Gold Hill, the upper level of the Little Grey mine, and the ridge back of the transformer house, 800 feet southeast of the Manhattan Ore & Milling Co.'s mill. At the last locality the gravel consists of 2 to 3 feet

¹ Jones, C. C., Notes on Manhattan placers, Nye County, Nev.: Eng. and Min. Jour., vol. 88, p. 103, 1907.

of hard cemented material, containing many boulders, particularly of the resistant porphyritic rhyolite. Below this hard material to bedrock is between 10 and 15 feet of loose sand and fine gravel. The coarse gravel is so well cemented as to require the use of a pick in mining, but the underlying sand is loose and unconsolidated. These gravels indicate a stage in the history of the gulch when its valley was wider than at present, and probably represent a period of comparative rest between epochs of greater erosion. Following the deposition of these gravels came renewed erosion, the result of which is shown in the buried canyon of the present gulch. As the canyon was worn down the greater part of these older gravels was moved gradually downstream and their gold content in part reconcentrated at favorable points on the new bedrock channels.

These remnants of the older gravels have not shown sufficient promise to lead to extensive prospecting. A lessee who has been mining the angular surface material on the north side of Gold Hill finds that the older gravel beneath does not carry gold in workable amounts. The only place where this older gravel was being mined at the time of the writer's visit was on the ridge south of the transformer house, where small irregular pay streaks were found in the coarse gravel above the fine sand. Probably the concentration of the gold in this gravel did not equal the later concentration effected by the stream which cut the canyon, and it is also likely that the small patches of older gravel remaining do not represent the pay streaks of the original stream.

GULCH GRAVELS.

In the gulch the pay gravel is covered by finer gravel and sand and this, in turn, by a roughly stratified deposit of more angular material. Complete sections were difficult to obtain, as the shafts which are not closely timbered are for the most part caved. The following sections, however, taken at intervals down the gulch, show the general type of the deposit.

A shaft near the southwest corner of the Mustang claim shows in its upper portion about 45 feet of roughly stratified, rather angular coarse and fine gravel. The upper 10 feet is largely rhyolitic, but below this material slate and gray schist are dominant. Near the base this gravel is much coarser than that in the upper portion and contains several boulders. Beneath this gravel for 15 feet are alternate bands, averaging about a foot in thickness, of clayey sand and fine gravel, the gravel about one-fourth inch in size. Below this material is 1 or 2 feet of half-inch gravel, which grades into the coarser pay gravel. The pay gravel here contains more boulders than that farther down the gulch. The boulders and pebbles are

embedded in a clayey matrix and sufficiently well cemented to stand without timber.

A shaft near the northwest corner of the Mustang extension (Copenhagen) claim, sunk 35 feet to one of the upper benches, shows about 30 feet of roughly stratified angular gravel, generally under 3 inches. Below this gravel is from 1 to 3 feet of loose rounded gravel of about half-inch size, with lenses of sandy clay. This loose gravel rests on 2 to 3 feet of the well-cemented pay gravel containing many boulders, chiefly of quartzite, the largest of which are 3 feet in diameter. Another shaft of the same depth, 250 feet south of the last, shows only 12 feet of the angular rhyolitic wash, but below this wash about 20 feet of fine gravel, the largest pebbles of which are not over 2 inches and which near the base consists chiefly of very fine uncemented slaty gravel. The 3-foot layer of pay gravel resting on bedrock is similar to that of the northern shaft.

A shaft at the mouth of Black Mammoth Gulch, near its junction with the main gulch, has a depth of 25 feet to bedrock. The upper 3 feet consists of bouldery material, chiefly rhyolite porphyry. Below this material is about 15 feet of bedded sand and pebbles, and the lower part consists of coarse gravels and angular boulders, the largest of which are about 1 foot in diameter.

On the African claim a 65-foot shaft on the southern branch of the channel shows 10 feet of very roughly stratified material, chiefly fragments of rhyolite. Below this comes 40 feet of evenly bedded fine gravel and sand, the gravel layers averaging about 1 foot in thickness and the sand layers 3 feet. From this level to the top of the pay gravel is uncemented very fine slaty gravel, the "chicken feed" of the placer miners. This fine gravel contains rare sandy lenses, but for the most part shows only very imperfect sorting. In the shaft the contact between the upper sand series and the fine slaty gravel dips 45° N., which is evidence of shifting stream channels. The pay gravel rests on a bedrock of dark crumpled slate and is from

The next shaft from which a section was obtained is on the Last Chance claim. Here the pay gravel is 1 to 6 feet thick and is covered with fine slaty gravel of the same type. A bench 4 feet above the main channel and 50 feet to the north shows similar conditions, except that here the pay gravel is rusty in appearance and in places irregularly stained with iron and manganese oxides. A second bench, to the south of the main channel and 15 to 20 feet higher, shows very little of this fine gravel, and the pay gravel is covered by clay and fine sand.

The China shaft, near the west end of the gulch, is 105 feet deep. The upper part to a point within 12 feet of bedrock consists of roughly stratified gravel, for the most part angular but without boulders. Below this gravel lies 10 feet of fine dark sand, chiefly

composed of minute slate fragments, containing lenses of clay. At the base of this stratum are a few boulders of quartzite and rhyolite porphyry from 1 to 2 feet in diameter but without any material intermediate in size. The thickness of the pay gravel is here 2 feet but increases to 6 feet about 50 feet north of the shaft. The material is finer than higher up the gulch, and though it contains a few boulders most of the gravel is less than 2 inches in diameter and the clayey cement of the upper claims is lacking. Still farther down the gulch the pay gravel is said to increase in thickness to 10 feet or more.

It is possible from the evidence at hand to reconstruct the history of the gulch. The older gravels found on the edges of the valley represent one or more stages in the early erosion of the gulch. After this early erosion the stream began to cut its canyon and the older gravels were largely eroded off, their gold content going to enrich the present deep gravels.

The present bench gravels represent stages in the process of canyon cutting. The lower gravels seem to indicate deposition by a swift-flowing stream which lost grade as it entered Big Smoky Valley, as is indicated by the smaller size of the pebbles and the thickening of the gravel near the mouth of the gulch. The waters, in time of flood at least, were capable of handling rather large boulders, and the whole mass of material was in fairly continuous motion toward the valley. Fragments of bone have from time to time been recovered from this gravel and material from the mines in the vicinity of Central, collected by Mr. L. F. Clar, was submitted to Mr. J. W. Gidley, of the National Museum, for identification. Mr. Gidley reports as follows:

M 601. *Elephas* sp.: tusk, very badly broken.

M 602. *Equus* sp.: distal end of tibia, metatarsus, and other fragments. Cervid, cf. *Rangifer* sp.: parts of tibia and metatarsal. Both are probably Pleistocene.

M 603. *Equus* sp.: upper molar. Probably Pleistocene.

The bones were found scattered and are broken, but they were probably deposited during the bench or deep-channel period of erosion and not in the older gravels, otherwise they would hardly have survived, even in their present fragmentary state. The fossils seem to indicate that a less arid climate then prevailed. In all probability the period in which the canyon cutting was accomplished and the lower gravels laid down is to be correlated with the existence of the Pleistocene Lake Toyabe in the northern part of Big Smoky Valley.

The fine material above the coarse pay gravel indicates decrease in the carrying power of the stream, which changed to an aggrading rather than a down-cutting stream. This change was probably due

to increasing aridity of climate rather than to any decrease in grade and perhaps was also consequent upon loss of part of its drainage area. From this time on there was probably little gold added to the pay gravels on bedrock. A few fragmentary plant remains were found in the clay lenses and finer sands, but none were sufficiently well preserved to admit of determination. The succession of stratified sand and fine gravel indicates a stream which was dominantly aggrading, and though in times of flood it scoured out new channels, it did not move the material directly above bedrock.

The last chapter of the stream's history is told by the poorly sorted rhyolitic material, which is found next the surface in the upper part of the gulch. This type of deposit indicates that there was no longer a constant surface flow but that this material was brought down from the hills to the north by the occasional heavy floods which are a feature of the present climatic conditions.

The gulch gravels have been productive over a distance of about 4 miles, beginning north of Gold Hill and extending down the gulch to the point where the stream valley makes its sharp turn to the north. Below this point a little work has been done, but the gold was found to be too finely divided and scattered throughout too thick a bed of gravel to be profitable for drift mining as at present conducted. North of Gold Hill there has been some work done from shafts at the lower end of town, but the deep gravels above town as well as those above Dublin, Consolidated, Slaughterhouse, and Black Mammoth gulches have not proved profitable. As gravel with a gold content of much less than \$2 a cubic yard is rarely mined, it follows that the parts of the gulch worked represent only those in which gravel showed the greatest concentration of gold. The richest portion of the gulch, now largely worked out, was the part between the sharp bend opposite Wolfe Tone Point and African Point. Here the deep channel splits into several smaller ones and some of the gravel was extremely rich. One of these channels is said to have yielded over \$50 a cubic yard across a face of more than 20 feet.

The gravels of the benches generally appear to be less valuable than those of the deep channel. On the Boston and Auction claims, however, these bench gravels were extraordinarily rich, probably because the northward-flowing Auction Gulch brought down much gold from the mineralized region just west of Gold Hill. According to information from Mr. Clar, however, the ground 500 feet up Auction Gulch showed no pay.

Only the bedrock gravel has proved workable, but gold is found in small amount throughout the gravel section. On one of the western claims a lens of coarse gravel above the fine material overlying the pay gravel was estimated to carry as much as \$2 a cubic yard.

Streaks here and there in the finer upper gravels may show colors to the value of 50 cents a cubic yard.

The writer desires to acknowledge his indebtedness to Mr. L. F. Clar for the following notes as to the richness of the various claims. These are quoted almost verbatim from his letter of February 19, 1915, to Mr. J. M. Hill.

The December Fraction and Copenhagen (Mustang extension) were very rich pieces of ground. The Wolfe Tone, Rainbow, and Sunrise were all good, but what may be considered as the very best piece in the gulch is the Little Wedge and the adjacent portion of the African and Searchlight. The Little Wedge is the small triangular area bounded by the Searchlight, Auction, and African claims.

The southern part of the Wolfe Tone Fraction proved somewhat of a disappointment to the operators.

The southeastern part of the September and the northern part of the Boston, together with the intervening wedge formed by the southern part of the Searchlight, were all good ground.

The northeast corner of the Auction showed up well, but the greater part of this ground is still unworked.

Downstream the ground proved less profitable as far west as the Central City claim. From this claim westward the placers have all shown good ground as far down the gulch as the Jumbo No. 2. The Robust claim, in which the deep channel is dry, had a pay streak which yielded \$7 a cubic yard.

The gulch narrows greatly at the lower end of the Happy Day, and the benches are lost. Below the Jumbo No. 2 the gravel is again poorer until the good ground of the Japan is reached. Westward from this claim the gulch is not sufficiently developed to furnish any information as to the comparative richness of the different claims.

Mr. Clar's notes seem to indicate that in a general way the richer parts of the gulch are those in which the stream flows along a more or less graded stretch above a steeper interval, or, in other words, where there has been some impounding of the gravel.

Although gold in workable amounts is concentrated in the coarse gravel close to bedrock, there are small amounts of gold in all the material from the coarse gravel to the surface. Except for the single upper lens of coarse gravel mentioned on page 183 there seems to be no concentration in the upper gravels, but the gold is scattered evenly through them, as would be expected in a deposit formed by an aggrading stream. As far as known these upper gravels nowhere carry more than 50 cents a cubic yard.

RECENT WASH.

Placer deposits consisting of recent wash have been worked in the neighborhood of Gold Hill and to some extent in the hills north and northeast of Central. These deposits yielded good returns, but were soon exhausted, and at the time of the writer's visit the only work on this type of deposit consisted in scraping the hillside north of the Big Four mine. The material consists of angular fragments of schist with little veinlets of gold-bearing quartz. The gold is coarse and angular, evenly distributed throughout the 2 or 3 feet of angular schist débris. This material rests on older gravel, which, however, does not contain sufficient gold to be workable.

THE GOLD.

No records have been kept with reference to the coarseness of the gold, but the operators agree that the size of the gold particles decreases gradually downstream. Fairly coarse nuggets, the largest of which were an ounce or more in weight, have been found in the upper half of the gulch. In the shafts in the extreme western part, however, the finely divided state of the gold is one of the chief difficulties of mining. Coarse gold is found throughout the gulch. In all the small samples of concentrates collected by the writer, from the portion of the gulch between the Wolfe Tone and Amboy claims, the majority of the gold colors were rather thin flakes exceeding 0.5 millimeter (40-mesh) in size, although few were greater than 1 millimeter (20-mesh).

For the most part the gold shows very little effect of abrasion and is usually arborescent or feathery in shape. The larger pieces almost invariably contain some quartz. The gold from the deep channel is clean and bright, whereas most of that from the pay streaks on the dry benches is slightly rusty and amalgamates less readily.

Of particular interest is the difference in purity of the gold in different parts of the gulch. The placer gold of the gulch, even in the vicinity of Gold Hill, is probably slightly finer than the gold of the lodes from which it is derived. Down the gulch to the westward the grade of the gold increases with the distance from its source. The fineness of the gold from the different claims, as determined from data collected by the writer and Mr. L. F. Clar, is shown in the accompanying table and the curve (fig. 19).

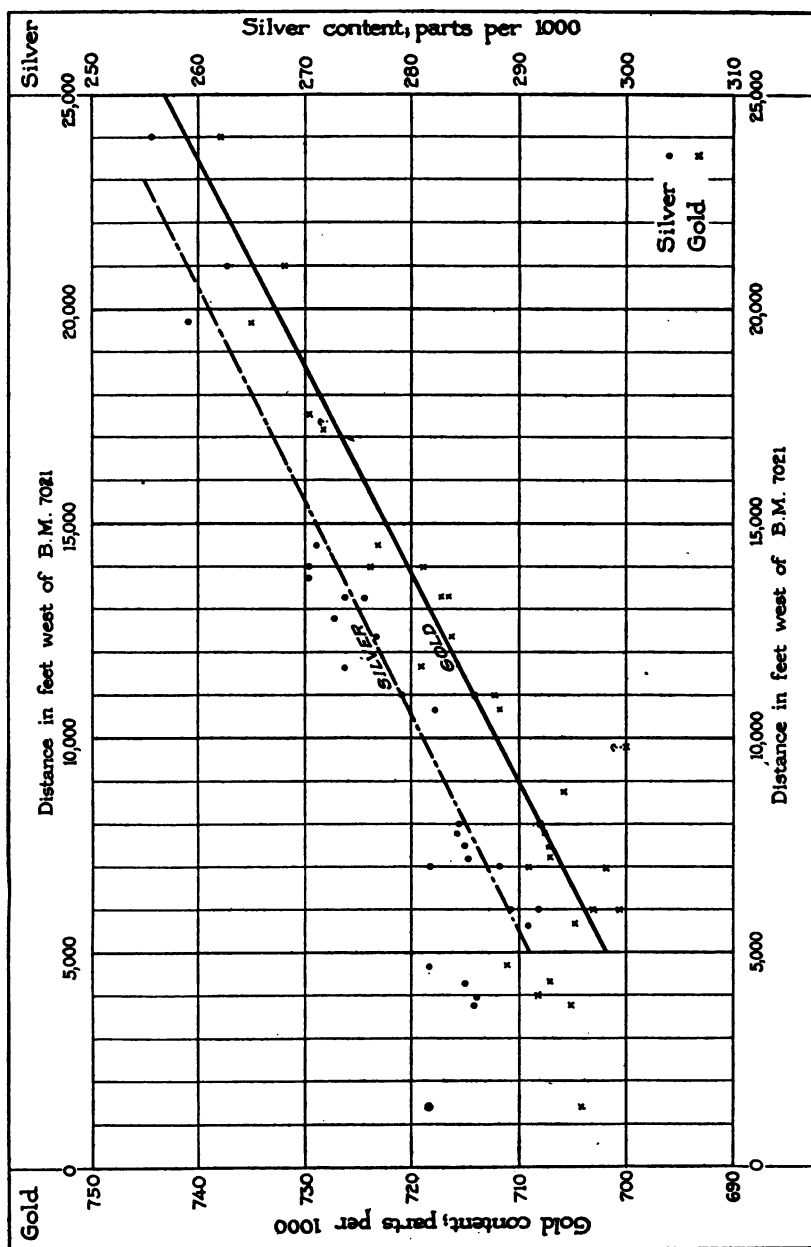


FIGURE 19.—Curve showing variations in fineness in placer gold of Manhattan district, Nev.

Variations in fineness of Manhattan placer gold.

Claim.	Approximate distance below B. M. 7021.	Gold (parts per 1,000).	Silver (parts per 1,000).	Base metals (parts per 1,000).	Remarks.
Dexter 14.....	<i>Feet.</i> 1,400	704.5	281.2	14.3	From deep gravel, single clean-up return. Most of the placer production of this claim was derived from the hillside wash, the gold of which showed a greatly varying fineness with a maximum of 0.690.
Mustang Extension (Copenhagen).	3,800	705.5	285.4	9.1	Upper end of claim. Average of 11 clean-up returns. Maximum variation 10 parts per 1,000.
Do.....	4,300	707.3	284.9	7.8	Middle of claim. Average of 27 clean-up returns. Maximum variation 17 parts per 1,000.
Do.....	4,800	707.8	285.9	6.3	Data furnished by Mr. L. F. Clar, who states that individual returns show greater irregularity than those from the lower part of the gulch.
Do.....	4,700	711.3	281.3	7.4	Lower end of claim. Average of 21 clean-up returns. Maximum variation 13 parts per 1,000.
Wolfe Tone.....	5,700	703.3	290.9	5.8	Average of 11 clean-up returns. Maximum variation 4 parts per 1,000.
Do.....	5,700	705			Operator's estimate.
Rainbow, Sunrise, and African.	6,000	700.8	289.0	9.3	Data furnished by Mr. L. F. Clar.
Sunrise.....	6,000	703.2	291.6	5.2	Average of 5 clean-up returns. Maximum variation 3 parts per 1,000.
Auction.....	7,000	709.5	281.5	9.0	Average of 6 clean-up returns. Maximum variation 11 parts per 1,000.
Do.....	7,000	702.0	288.0	10.0	Gold derived from bench gravels. Data furnished by Mr. L. F. Clar.
Boston.....	7,200	707.2	285.0	7.8	Gold derived from bench gravels.
Do.....	7,500	707.5	284.75	7.75	Do.
Do.....	7,800	707.7	284.0	8.3	Average of 12 clean-up returns. Maximum variation 6 parts per 1,000.
September.....	8,000	708.4	284.1	7.5	Gold derived from bench gravels. Data furnished by Mr. L. F. Clar.
Do.....	8,000	708.95	285.5	6.55	Gold derived from bench gravels.
Top Knob.....	9,000	706.0			Data furnished by Mr. L. F. Clar.
Pedro.....	10,700	712.0	282.0	6.0	Operator's estimate.
Robust.....	11,000	714.5	279.0	6.5	Data furnished by Mr. L. F. Clar.
Do.....	11,000	712.5	279.0	8.5	Do.
Morning Star.....	11,700	675	257	68.0	Average of 2 clean-up returns.
		(719.2)	(273.8)	(7.0)	Data furnished by Mr. L. F. Clar.
Black Cat.....	12,400	706	274	20	Data furnished by Mr. L. F. Clar.
		(716.4)	(276.6)	(7.0)	Gold obtained from reworking old dumps and contains much foreign material. Recalculated on a basis of 7 parts base metal (average of Pedro and Robust) shows fineness given in parentheses.
Do.....	12,800	709	270	21	Data furnished by Mr. L. F. Clar.
		(720.2)	(272.8)	(7.0)	Recalculated as above.
Last Chance.....	13,300	717.25	273.75	9.0	Average of 4 clean-up returns. Maximum variation 4 parts per 1,000.
Do.....	13,300	716.7	275.5	7.8	Data furnished by Mr. L. F. Clar.
Foolem.....	14,000	724.0	270.2	5.8	Average of 6 clean-up returns. Maximum variation 7 parts per 1,000.
Do.....	14,000	719.0	273.0	8.0	Data furnished by Mr. L. F. Clar.
Georkey and Edith.....	14,500	723.25	271.0	5.75	Do.
Arlington.....	17,200	714-738			Operator's estimate. (See text, p. —.)
Arlington and Amboy.....	17,500	729.64	264.18	6.18	Most gold taken from bench gravels, of which fineness is said to be between 0.719 and 0.738.
Amboy.....	17,800	700-740			Data furnished by Mr. L. F. Clar.
Bright August.....	19,700	735	259	6.0	Operator's estimate.
Happy Day.....	21,000	732	262.5	5.5	Data furnished by Mr. L. F. Clar.
Japan.....	24,000	738	255.5	6.5	Average of 2 clean-up returns.
					Data furnished by Mr. L. F. Clar.

The highest claim in which the deep gravels have been worked is the Dexter 14, just below the town of Manhattan. No data are available for the deep placer gravels of the Little Grey and Nellie Grey claims next below, but on the Mustang Extension (Copenhagen) the gold shows a marked increase in fineness over that from the Dexter 14. The next claim from which data were obtained is the Wolfe Tone, just below the sharp bend at Wolfe Tone Point. Here the fineness is 8 parts per 1,000 less than that of the gold from the lower end of the Mustang Extension. This claim, however, was famous for the coarseness of its gold. Below this point the grade of the gold increases proportionately with the distance downstream, in the ratio of 1.6 parts per 1,000 to each 1,000 feet. The richer parts of the deep channel all lie below Wolfe Tone Point, and it is believed that the greater proportion of the gold mined from the deep channel entered the gulch at about this point, probably along Auction Gulch.

The average fineness of all placer gold produced during the six years for which figures are available likewise shows a steady increase, due, it is believed, to increased development in the lower part of the gulch and to the exhaustion of the surface placers on Gold Hill, as well as to better methods of mining, which resulted in the saving of a larger proportion of the smaller gold particles. The averages for lode gold, however, as derived from the totals in the volumes of Mineral Resources of the United States for the years 1908-1914, show great irregularity. For the years 1908 to 1912, inclusive, the average fineness ranged between 0.657 and 0.702. During 1913 and 1914, however, the fineness of the gold was 0.748 and 0.731, respectively. This is believed to be due to the fact that these two years mark the greatest period of activity of the White Cap mine. There is practically no silver in the ore from this mine, but as the gold is not free this type of ore has no effect on the fineness of the placer gold. The fineness of the lode gold, as indicated by mint certificates, shows great variety. For the following figures the writer is indebted to Mr. L. F. Clar. Gold from the limestone lodes on April Fool and Litigation hills had a fineness ranging from 0.527 to 0.740, with an average of about 0.680. The gold from the prospects in the rhyolite on Bald Mountain was even baser, about 0.500. A part at least of the gold from Gold Hill (Big Pine and Big Four) was as fine as 0.717.

Fineness of Manhattan lode and placer gold.

Year.	Lode.	Placer.	Year.	Lode.	Placer.
1908.....	0.664		1912.....	0.601	0.716
1909.....	.657	0.703	1913.....	.748	.721
1910.....	.675	.709	1914.....	.731	.731
1911.....	.702	.706			

The cause of the regular increase in fineness toward the mouth of the gulch is believed to be due to the solution, through long action of the surface water, of a portion of the silver and nearly all the base metal contained in the gold. To raise a mass of gold containing originally 700 parts gold and 300 parts silver to a fineness of 0.733 would require the removal of 15 per cent by weight of the silver, or about 4.5 per cent of the whole mass. As has been shown above, a part of the gold has undoubtedly been derived from the older gravels, and all the gold in the lower gravels, whether added to the placers at the end of the canyon-cutting period or reconcentrated from the older gravels, has certainly been exposed for a long time to the action of whatever solvent may be present in the water. Placer gold is commonly purer than the lode gold from which it is derived, as for instance in the Tertiary gravels of California,¹ and Smith² has shown that the gold of certain gulch placers of Alaska likewise increases in purity away from the source, but at Manhattan the great increase in a short distance and the regularity of increase are unusually well marked.

Although the regularity of the increase in fineness points clearly to a process of refining through solution by means of waters rendered acid through the oxidation of pyrite, it is not easy to imagine how this is accomplished. The proportion of "base metal," believed to be chiefly copper, represented by the difference between 1,000 and the sum of the figures for gold and silver, does not decrease greatly downstream, and it is difficult to conceive of a solvent capable of attacking the silver without removing the "base metal" as well. Furthermore, the ordinary solvents of the laboratory are not effective in "parting" the silver when alloyed in such small proportion with the gold.³ It has been suggested that to account for this increase in fineness, so generally observable in placers, it is necessary to suppose that both gold and silver are to some extent dissolved but that the greater part of gold is soon redeposited.⁴ But there is nothing in the appearance of the Manhattan Gulch gold which would tend to confirm this hypothesis.

It is not possible to draw any conclusions as to the possible solvents present in the water. The oxidation of pyrite may have given a slightly acid solution; iron salts, such as ferric chloride, may have been present, or the solution of a part of the fluorite might possibly have given the underground waters a minute amount of hydrofluoric acid.

¹ Lindgren, Waldemar, *The Tertiary gravels of the Sierra Nevada of California*: U. S. Geol. Survey Prof. Paper 73, p. 69, 1911.

² Smith, P. S., *The fineness of gold in the Fairbanks district, Alaska*: Econ. Geology, vol. 8, pp. 449-454, 1913.

³ Rose, T. K., *The metallurgy of gold*, pp. 97, 439-445, 6th ed., London, 1915.

⁴ Idem, p. 97.

The important factors are, however, the length of time in which the gold has remained undisturbed and subject to a constant flow of water and the decrease in the average size of the gold particles with their distance from the source. As has been shown, the gold of the lower gravels has remained in its present position since Pleistocene time, and moreover a part of the gold was derived from the earlier placers represented by the older gravels. The size of the gold particles, as is natural to expect, likewise decreases down the gulch, the coarser and more compact nuggets being more common in the portion immediately below Gold Hill and the lower placers containing the greater amount of fine scaly gold. The fine gold, of course, offers a greater surface to the solvents contained in the stream water and hence has attained a higher degree of purity. The increase in purity of the gold is therefore believed to be dependent on the distance from the source only in so far as the gold has been sorted by size in transportation. The regular increase in proportion to distance shown by the curve (fig. 19) is believed to be in large measure a function of the decrease in size of the gold particles. If the gold particles were of the same average size on each claim the fineness should be approximately the same throughout the gulch, for as the bulk of the gold has been in its position since Pleistocene time, the difference in opportunity for solution between the head and mouth of the gulch would be negligible. If data were available a similar curve showing decrease in average size of grain downstream would probably exhibit an equal degree of regularity.

Another factor which may possibly have had some influence on the fineness of the gold is the increase in purity through oxidation of the outcrop. As the formation of the veins antedates the mature topography, remnants of which are preserved in the central part of the range, the outcrops must have been subjected to a long period of weathering, during which the gold would be to some extent refined in place through solution of the silver. Thus the gold fed to the placers may have been purer at the start, though with an increasingly high silver content as the rapid erosion of Manhattan Gulch outstripped oxidation. It is therefore possible that a portion of the gold near the mouth of the gulch represents material taken from a higher horizon in the veins.

Mr. Clar considers that it is possible that the rich stringers on Georgey Hill and elsewhere down the gulch added enough purer gold to bring up the average fineness of the gold in the lower claims. The regularity of the increase, as shown by figure 19, seems to make this impossible. Moreover, these smaller veins are insignificant in comparison with the metallized area around Gold Hill, and if they had added a sufficient amount of gold to raise the average fineness to

the points shown on the curve the increase in the tenor of the gravels of the lower gulch would have been enormous.

No data are available in regard to possible differences in size or purity of the gold of the benches and the deep channel. The Boston claim derives its entire output from a bench 15 feet above the deep channel but shows the same degree of fineness in respect to its distance from the source as the others. On the other hand, it is said that tests of gold from the Arlington claim show differences in fineness as follows: Gold from upper bench, 30 feet below surface, \$15.20 to \$15.35 an ounce; gold from lower bench, 40 feet below surface, \$15 to \$15.10 an ounce; gold from deep channel, 60 feet below surface, \$14.90 an ounce.

This observation is, however, an isolated one, and it is not possible to draw definite conclusions. It may be that in this locality, where the benches are more sharply defined than usual, the gold on the benches was derived from a more oxidized portion of the vein during an earlier period of stream erosion, and is therefore purer. Or it may be that local conditions favored the accumulation of finer gold on the benches than in the main channel. Although the deep channel alone has a constant flow of water, and the silver might therefore be supposed to be more completely dissolved, the bench gravels are everywhere moist, owing to seepage from the valley sides.

The gold from the surface placers on the north side of Gold Hill has a very low fineness. The different clean-up returns show great variation, due to foreign matter, such as shot, included with the bullion; but the gold has a maximum fineness not exceeding 0.680, which is distinctly lower than the reported fineness of the lode gold at present mined on Gold Hill.

OTHER MINERALS.

Aside from gold no other valuable minerals are recovered from the placers. The concentrates contain a large amount of barite, which is sometimes found in pebbles an inch or more in length. No such large masses were seen in any of the veins, although barite in small crystals is not uncommon as a gangue mineral in some of the Gold Hill veins.

As usual in placer deposits, the concentrates contain a large proportion of magnetite, but in many of the samples collected this is exceeded in volume by the barite. Magnetite occurs in minute sharp octahedra, nearly all of which pass through a 40-mesh sieve. The size of the grains probably averages about 0.3 millimeter. A small proportion of the black sand is nonmagnetic and appears to consist principally of psilomelane.

Cinnabar is reported from a number of the placer mines, but only very minute specks were present in the samples of concentrates collected by the writer. Although this mineral is not common in the district, it has been reported in the ore of the White Cap mine, and cinnabar prospects have been worked in the mountains to the north.

Fresh pyrite was found only in very rare minute specks. Small cubes completely altered to limonite are, however, fairly common.

Fluorite is a common gangue mineral in the mines of Mustang, April Fool, and Litigation hills, but it is extremely rare in placer concentrates, only two or three small specks being seen.

Besides these heavy minerals the average sample of concentrates contains many minute fragments of schist, the smallest a millimeter in size, quartz both as fragments of crystals from the veins and as small dihexagonal pyramids weathered out of the porphyritic rhyolite, and small feldspar crystals.

MINING METHODS.

The first placer work done in the district consisted of surface work in the vicinity of Gold Hill and Indian Camp. Water was scarce and the work was carried on either by means of dry-washing machines or by sluicing with a carefully conserved supply of water. The following notes, quoted from Mr. Packard's paper,¹ give an interesting description of the method of sluicing:

Here water is hauled in barrels and dumped into a large tank. The gravel is shoveled upon a platform, * * * and the water from the tank is then drawn off through the sluice box, the gravel being fed in from the platform. The water from the sluice returns to a pit dug below the tank. It is then raised in a box attached to one end of the long pole. * * * To do this a man walks up the plank, * * * and, jumping off, catches hold of the other end of the pole and, lying over it, his weight brings the box up to the level of the top of the tank, and the water is then automatically discharged into the tank for further use.

The saving by the dry-washing machines is not claimed to be over 70 per cent, while the saving by the Manhattan method is undoubtedly much higher. The disadvantages of the latter method lie in decreased capacity, greater expense, and the difficulty of finding a man whose stomach will stand the pressure necessary for operating the pole for a longer time than is absolutely necessary to secure money enough to last while hunting another job.

The water pumped from the neighboring lode mines is now available and sufficient in quantity for the small amount of work still done on the surface placers.

The placers of the gulch are all worked by drift mining, as the overburden is too thick for dredging or hydraulicking, even if there were sufficient water available. An attempt at mining by means of a suction pipe resulted in failure.

¹ Packard, G. A., Round Mountain camp, Nev.: Eng. and Min. Jour., vol. 83, p. 151, 1907.

There is a constant flow of water through the pay gravels along the greater part of the deep channel. This flow ranges from 20,000 to 50,000 gallons a day, generally nearer the larger amount, but fails entirely in two places, where the canyon crosses limestone strata and the water is probably diverted to crevices or solution channels.

The water used for washing the gravels is pumped from the wet channel to small ponds below the sluice boxes and from there is pumped to the sluice boxes. The water is thus used continuously, and the amount obtained by pumping compensates for the losses from seepage and evaporation. Drifts are run in the pay gravel for a maximum distance of 300 feet from the shaft, and the pay streak is developed by short crosscuts. It is considered more economical to sink a new shaft than to increase the length of the drift beyond 300 feet. When the pay streak has been developed the gravel is stoped back toward the shaft after the manner of longwall coal mining. The schistose bedrock contains many small crevices in which the gold can lodge and is therefore removed to a depth of about a foot. The coarse, clayey gravel stands well, and few supports are needed in the stopes. Boulders too large to be handled easily are not hoisted but are left behind as the work progresses. In most mines the tramming is done by wheelbarrows, but, in a few, tracks have been laid and the dirt taken in cars to a bin instead of directly to the shaft bucket. The power line of the Nevada-California Power Co. entered Manhattan Gulch in 1909, so electric pumps and hoists have supplanted the gasoline engine.

The gravels after screening pass to the sluice boxes. At some mines a quicksilver trap, which takes most of the coarse gold, is placed near the head of the boxes. Usually there are two sets of boxes, each about 20 feet long, provided with Hungarian riffles and set at an angle of 5° or 6°. By far the greater part of the gold is, however, recovered in the upper few feet. The writer was informed that in a clean-up of 50 ounces at the Last Chance mine only three-eighths of an ounce was recovered from the lower half of the boxes. Working in winter entails considerable loss unless great care is taken, owing to the freezing of the water between the riffles. As all precautions were neglected in the early days of mining, it has been found profitable to rework many of the old dumps.

No accurate account of costs has been kept at any of the mines, but it is the general opinion that in a well-equipped mine the cost of mining is rather more than \$1 a cubic yard. At present there are very few operators working their own claims. Most of the work is being done by Serbian and Italian lessees, who are mining small patches of pay gravel left behind during the earlier operations.

DEPARTMENT OF THE INTERIOR
FRANKLIN K. LANE, Secretary

UNITED STATES GEOLOGICAL SURVEY
GEORGE OTIS SMITH, Director

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THE
GARRISON AND PHILIPSBURG PHOSPHATE
FIELDS, MONTANA

BY

J. T. PARDEE

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THE GARRISON AND PHILIPSBURG PHOSPHATE FIELDS, MONTANA.

By J. T. PARDEE.

FIELD WORK.

The field work upon which the present report is based was done between August 24 and October 25, 1913. The time was expended principally on the area north of Garrison and Drummond, Mont.,

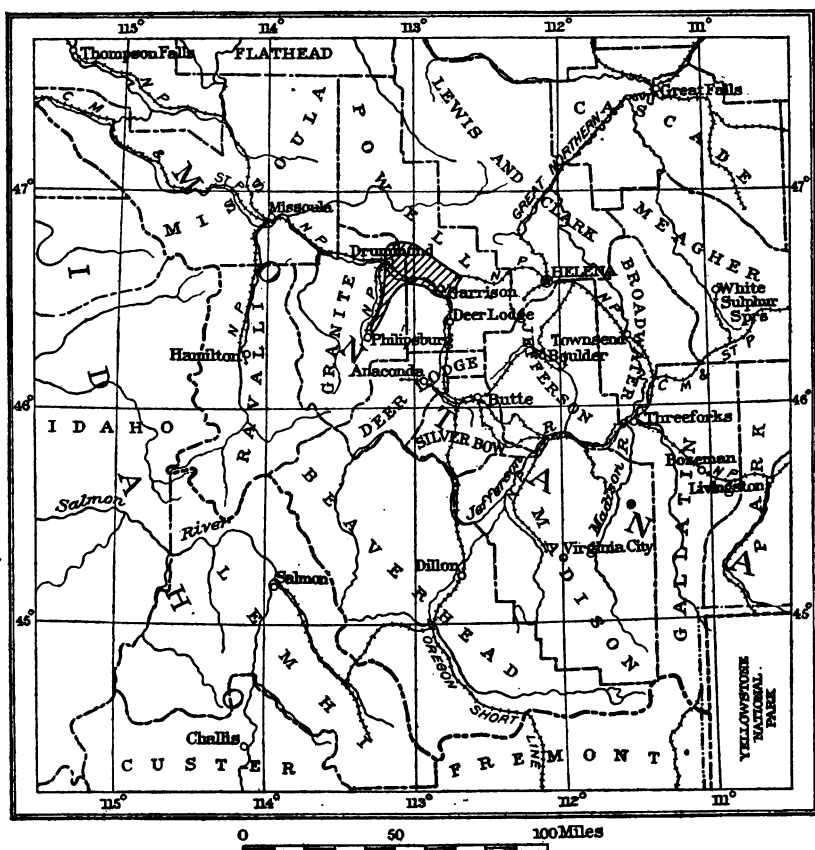


FIGURE 20.—Index map showing location of Garrison and Philipsburg phosphate fields, Mont. Area covered by this report indicated by shading.

referred to as the Garrison field, but a brief examination of the Philipsburg and Maxville localities in the Philipsburg field was made also. (See fig. 20.)

For a base map of the Garrison field the township plats of the General Land Office were utilized, and, in addition, a plane-table survey was projected across the area. As the belt along which the phosphate bed would normally be exposed at the surface is nearly everywhere occupied by deep soil or rock débris, trenches were dug at several points to obtain samples and measurements. Although in the present examination attention was directed chiefly to the outcrop of the phosphate-bearing stratum, sufficient work

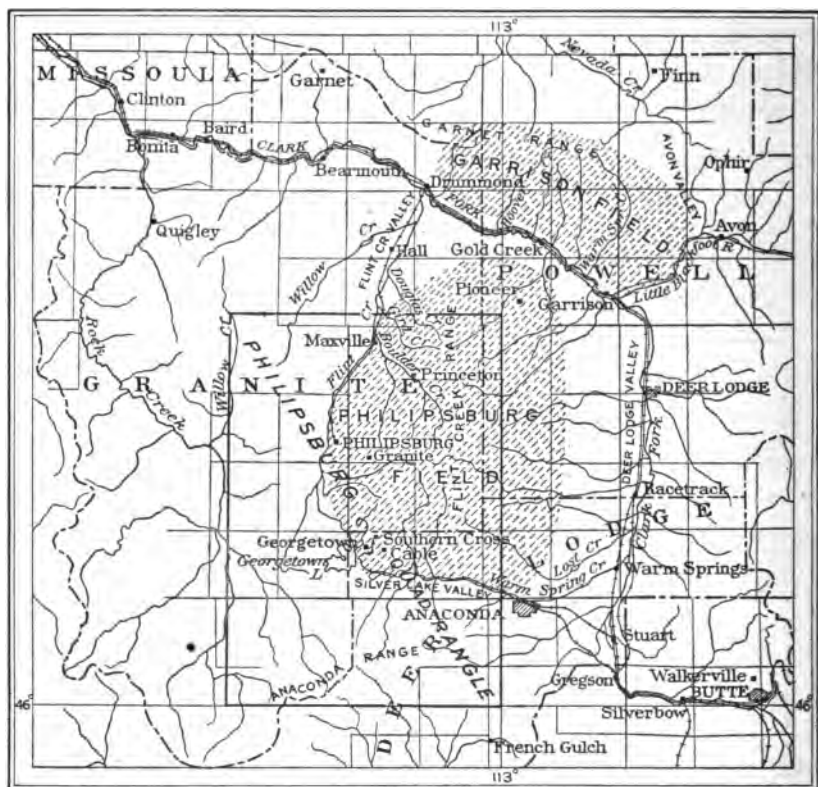


FIGURE 21.—Map showing relation of the Garrison and Phillipsburg phosphate fields, Mont., to the Phillipsburg quadrangle.

was done in adjoining lands to determine the general succession and structure of the several rock formations, knowledge of which is absolutely essential to a correct estimate of the phosphate deposit. The present survey was tied to others made in the same region in 1910¹ and 1911.² The writer was assisted in the field by T. H. Rosenkranz, to whose accurate mapping the knowledge attained

¹Pardee, J. T., Coal in the Tertiary lake beds of southwestern Montana: U. S. Geol. Survey Bull. 531, pp. 229-244, 1913.

²Pardee, J. T., Some further discoveries of rock phosphate in Montana: U. S. Geol. Survey Bull. 530, pp. 285-291, 1913.

of the stratigraphy and structure is in large part due. Mr. Rosenkranz has also aided in the preparation of the present report by the contribution of rock analyses and other researches, contained in an unpublished thesis.

The southwestern three-fourths of the Philipsburg field, including the Philipsburg and Maxville localities, lies within the Philipsburg quadrangle (fig. 21), the exceedingly intricate geology of which was worked out in detail in 1906-1908 by F. C. Calkins.¹ In the Philipsburg quadrangle, therefore, the probable distribution of the phosphate deposit, as shown by outcrops of its inclosing rocks, is already known. Its actual presence or absence, dimensions, and other features, however, remain to be determined. In the course of the present investigation the phosphate bed was uncovered at Philipsburg by trenching and was sampled near Maxville in a tunnel already made by private enterprise.

The geology of that portion of the Philipsburg field north of the Philipsburg quadrangle is not known in detail. As the area is relatively small, however, some of the broader generalizations based on knowledge of the surrounding country may be applied to it.

SUMMARY.

The economic results of the present investigation may be briefly summarized as follows:

Workable deposits of high-grade rock phosphate (containing 60 per cent or more tricalcium phosphate) occur in both the Garrison and Philipsburg fields. That in the Garrison field lies from 6 to 10 miles north of the town of Garrison and is easily accessible, and the portion considered as available to mining contains by estimate 97,000,000 long tons (equivalent to 108,640,000 short tons of 2,000 pounds), an amount about twice as great as the total production of the United States to date. About one-third of the amount lies above the natural drainage levels, and much of this portion can be very readily extracted by means of adits driven along the phosphate bed.

In the Philipsburg field too little work has been done to justify a tonnage estimate, but the deposits are believed to be extensive, and are known to be in two places at least of workable size and readily available to mining.

LITERATURE.

Many papers have been published dealing with the geology of the territory that may be included within the western phosphate region. The principal reports that describe the phosphate deposits, together

¹ Emmons, W. H., and Calkins, F. C., *Geology and ore deposits of the Philipsburg quadrangle, Mont.*: U. S. Geol. Survey Prof. Paper 78, 1913. Calkins, F. C., and Emmons, W. H., *U. S. Geol. Survey Geol. Atlas, Philipsburg folio* (No. 196), 1915.

with a few others that describe the geology of the particular area under consideration, are listed below, in order of publication:

Gale, H. S., and Richards, R. W., Preliminary report on the phosphate deposits in southeastern Idaho and adjacent parts of Wyoming and Utah: U. S. Geol. Survey Bull. 430, pp. 457-535, 1910.

Blackwelder, Elliot, Phosphate deposits east of Ogden, Utah: U. S. Geol. Survey Bull. 430, pp. 536-551, 1910.

Girty, G. H., The fauna of the phosphate beds of the Park City formation in Idaho, Utah, and Wyoming: U. S. Geol. Survey Bull. 436, 1910.

Gale, H. S., Rock phosphate near Melfose, Mont.: U. S. Geol. Survey Bull. 470, pp. 440-451, 1911.

Richards, R. W., and Mansfield, G. R., Preliminary report on a portion of the Idaho phosphate reserve: U. S. Geol. Survey Bull. 470, pp. 371-439, 1911.

Pardee, J. T., Coal in the Tertiary lake beds of southwestern Montana: U. S. Geol. Survey Bull. 531, pp. 229-244, 1913.

Schultz, A. R., and Richards, R. W., A geologic reconnaissance in southeastern Idaho: U. S. Geol. Survey Bull. 530, pp. 267-284, 1913.

Pardee, J. T., Some further discoveries of rock phosphate in Montana: U. S. Geol. Survey Bull. 530, pp. 285-291, 1913.

Emmons, W. H., and Calkins, F. C., Geology and ore deposits of the Phillipsburg quadrangle, Mont.: U. S. Geol. Survey Prof. Paper 78, 1913.

Schultz, A. R., Geology and geography of a portion of Lincoln County, Wyo.: U. S. Geol. Survey Bull. 543, 1914.

Richards, R. W., and Mansfield, G. R., Geology of the phosphate deposits northeast of Georgetown, Idaho: U. S. Geol. Survey Bull. 577, 1914.

Stone, R. W., and Bonine, C. A., The Elliston phosphate field, Mont.: U. S. Geol. Survey Bull. 580, pp. 373-383, 1915.

Calkins, F. C., and Emmons W. H., U. S. Geol. Survey Geol. Atlas, Phillipsburg folio (No. 196), 1915.

Mansfield, G. R., A reconnaissance for phosphate in the Salt River Range, Wyo.: U. S. Geol. Survey Bull. 620, pp. 331-349, 1916.

GEOGRAPHY.

LOCATION AND ACCESSIBILITY.

The rock-phosphate deposits of the Western States are distributed over a large, indefinitely bounded area composed of adjoining parts of southwestern Montana, eastern Idaho, western Wyoming, and northern Utah and generally known as the western phosphate region. Of the several phosphate localities, those near Garrison and Philipsburg, Mont., which are the northwesternmost in the general region mentioned, are referred to herein as the Garrison and Philipsburg fields. Their limits can not, so far as present knowledge goes, be very definitely placed. For the purposes of the present report, however, the Garrison field may be defined as extending from Avon Valley west to the town of Drummond and from Clark Fork north to the summit of the Garnet Range or a little beyond. The Philipsburg field, which adjoins the Garrison field on the south, may be considered approximately equivalent to the area of the Flint

Creek Range, or that lying between the Deer Lodge and Flint Creek-Philipsburg valleys. The two fields combined cover the northeastern part of Granite County and a small adjoining part of Powell County, Mont.

The Garrison and Philipsburg fields lie a short distance west of the Continental Divide, within the drainage basin of Clark Fork of the Columbia (locally known as Deer Lodge River), and adjoin the principal mining and smelting section of the State. The river that divides them is closely followed by the main lines of the Northern Pacific and Chicago, Milwaukee & St. Paul railways, and the Philipsburg field is touched, in addition, by the Butte, Anaconda & Pacific Railway and the Philipsburg branch of the Northern Pacific.

The great agricultural region of the Mississippi Valley lies about 1,000 miles to the east, and the principal grain-growing localities of the Columbia basin are from 300 to 500 miles to the west. The seaports on the Pacific Ocean are about 700 miles west. In considering possible markets for the rock phosphate or its products, however, the facts that agricultural valleys of considerable extent are near by and that large areas in the Northwest heretofore considered suitable for grazing only are being brought under cultivation should not be overlooked.

TOPOGRAPHY.

Although western Montana contains many flat lowlands of notable size, much the larger part of it is occupied by mountains. As a rule the main lowlands, of which the Clark Fork valley is a typical example, separate the mountains into more or less detached groups. Of these the Garnet and Flint Creek ranges dominate, respectively, the areas referred to herein as the Garrison and Philipsburg fields.

From its blunt north end, which borders the Clark Fork valley for about 10 miles below Garrison, the Flint Creek Range extends south-southwestward a distance of about 30 miles. It is a broad, massive elevation that has an average summit level between 8,000 and 9,000 feet, or about 4,000 feet above the valleys on the east, west, and north. On the south it appears from most viewpoints as a large north spur of the imposing Anaconda Range, although as a matter of fact the two are distinctly but not widely separated by Silver Lake valley. In detail the surface of the Flint Creek Range is rugged, the northern part in particular being characterized by deep canyons and alpine peaks.

The Garnet Range is much less prominent than its neighbor to the south. The portion covered by the present report is about 25 miles long, trends west-northwest, and has a general elevation of about 6,500 feet. In distant views its broad summit appears nearly level and its contour rather smooth. In detail, however, it is seen to be

moderately dissected by streams and to have some fairly prominent ridges and peaks, of which the highest is Mount Baldy (elevation, 7,690 feet).

It is convenient, in describing this region, to conform to local usage of the terms "canyon" and "valley." As a rule, all the steep-walled, comparatively narrow mountain valleys are called canyons, and the term "valleys" is used only for the broader depressions that separate the principal mountain groups. Thus the canyons are the valleys within the mountain ranges, and the valleys are the lowlands between them. Furthermore, whether by accident or otherwise, this classification agrees with a geologic grouping based on age and origin. Thus the valleys date from early Tertiary time and are chiefly of structural origin, and the canyons are of late Tertiary or Quaternary age and due to erosion alone. That the local residents should have made such a classification is not surprising, in view of the differences not only in size but in the cross sections between the structural and erosional valleys. Cross sections of the structural valleys are similar in general to those of a shallow dish or bowl, the sloping sides of which gradually curve into the bottom, while cross sections of the erosional valleys are either V-shaped or show distinct angles at the junctions of the slopes and the level bottom. The canyons in the Garnet Range that dissect the phosphate deposits most extensively are those of Warm Spring Creek,¹ East Brock Creek, and Brock Creek. The Warm Spring Creek canyon, which begins about 5 miles above the junction of the stream with Clark Fork, is a rugged V-shaped trench 1,600 feet or more deep. The canyons of the other two streams are not so deep and precipitous but likewise extend well back into the range.

A part of the valley of Clark Fork and the lower part of the Flint Creek valley together form a large irregular basin, elongated in a southeast-northwest direction, which separates the Garnet and Flint Creek ranges. Its width is about 6 miles at Garrison and 12 or 15 miles at the widest point to the northwest. Clark Fork crosses the basin from southeast to northwest and lies somewhat north of the middle, rather close to the foot of the Garnet Range. Viewed generally, the inward slopes of the basin decrease gradually as they approach the river. Elevations along the river range from about 3,900 feet at Drummond to about 4,300 feet at Garrison, but between the river and the foot of the adjacent mountain slopes there is in places a difference of as much as 1,000 feet.

In detail the basin floor is dissected by rather narrow, shallow, geologically recent stream trenches separated by broad, flat-topped remnants of the basin floor known as bench lands.

¹ This creek should not be confused with the one of the same name that flows past Anaconda.

The Garrison and Philipsburg fields are well supplied with surface water. Several vigorous and persistent streams that are valuable for power and irrigation drain the Flint Creek Range. The streams of the Garnet Range, however, are much smaller and, except Warm Spring Creek, become low or dry in the summer. Warm Spring Creek is evidently so named because after sinking and flowing underground about 2 miles the water rises with a lukewarm temperature. It is interesting to observe, also, that where the stream reappears, near the mouth of the canyon, it is about doubled in volume, is extremely "hard" with calcium carbonate, and has built a dam of travertine or a similar limy deposit 60 feet high.

CLIMATE, VEGETATION, AND SETTLEMENTS.

In this region the precipitation is light or moderate and the temperature rather low. From observations covering a considerable period of time the mean annual temperature at Helena and Missoula, Mont.,¹ is determined to be 43° and 44° Fahrenheit, respectively, and the annual rainfall 13.3 and 15.5 inches. The stations mentioned are about 50 miles east and west of the Garrison field and occupy situations comparable to points in the Clark Fork and Flint Creek valley.

The climate, however, varies considerably from place to place, according to the altitude. The main valleys and the lower slopes, which probably have a temperature and a rainfall equivalent to the mean of those given, or 43½° Fahrenheit and 14.4 inches, respectively, are rather dry and have a climate mild enough to permit the cultivation of grains and hardy fruits. The amount of rain or snow fall and the cold increase with increase in altitude, and in the higher portions of the Flint Creek Range three-quarters of the year is wintry.

Some of the higher peaks of the Flint Creek Range project above timber line, but most of the area is covered above the 6,000-foot contour with a forest of lodgepole pine except where it has been stripped for fuel. The belt between the valley levels and 6,000 feet is partly timbered with varieties of fir, the trees being mostly segregated in groves on the northerly slopes, which retain moisture better than other exposures. The uncultivated parts of the valleys as a rule lack timber, but are thickly covered with bunch grass and other forage plants.

Outside of the principal mining districts in the Flint Creek Range the mountainous portions of the area contain few inhabitants. The valleys, however, have a considerable population and several towns.

¹ Henry, A. J., *Climatology of the United States*: U. S. Dept. Agr. Bull. Q, pp. 802, 804, 805, 1906.

Philipsburg (population 1,109, census of 1910), situated in a celebrated silver mining district at the west foot of the Flint Creek Range, is the most important. Maxville, formerly Flint, 12 miles to the north, and Georgetown, about the same distance to the south, are smaller mining camps.

At the southern foot of the Garnet Range are several agricultural settlements, of which the largest is Drummond and the one nearest to the main phosphate deposit is Garrison.

In addition to the mining and reduction of metalliferous ores, the principal industries of the region are stock raising and the cultivation of grains.

GEOLOGY.

STRATIGRAPHY.

PRE-TERTIARY SEDIMENTARY ROCKS.

GENERAL FEATURES.

The general succession of the pre-Tertiary sedimentary rocks occurring in the Garnet and Flint Creek ranges is shown by the following table. The column representing the Garnet Range is made up chiefly of sections measured along Warm Spring, Brock, and Hoover creeks; that for the Flint Creek Range is condensed from the report on Philipsburg quadrangle by Emmons and Calkins.¹

Generalized sections of pre-Tertiary sedimentary rocks in the Garnet and Flint Creek ranges, Mont.

Geologic age.	Formation.	Garnet Range.		Flint Creek Range.	
		Character.	Thickness (feet).	Character.	Thickness (feet).
Upper Cretaceous or Tertiary?		Conglomerate. Contains abundant pebbles and cobbles as much as 6 inches in diameter of Madison limestone, quadrant quartzite, and rocks probably of Ellis and Kootenai formations. Many beds of pale-yellow sandstone in upper portion. Top removed by erosion.	700+		
Cretaceous (Upper Cretaceous).	Colorado? or Montana?	Chiefly medium to fine buff-weathering, gray sandstone, also many variegated beds in which dull shades of green predominate, with some thin pink or purple beds near the top. Considerable dull-colored argillite in lower portion.	4,800		

¹ Emmons, W. H., and Calkins, F. C., *Geology and ore deposits of the Philipsburg quadrangle, Mont.*: U. S. Geol. Survey Prof. Paper, 78, 1918.

Generalized sections of pre-Tertiary sedimentary rocks in the Garnet and Flint Creek ranges, Mont.—Continued.

Geologic age.	Forma- tion.	Garnet Range.		Flint Creek Range.	
		Character.	Thick- ness (feet).	Character.	Thickness (feet).
Cretaceous (Upper Cretaceous)—Continued.	Colorado.	Alternate layers of buff to brown weathering, gray sandstone and dull-green to black shale. Some thin bands of limestone near top contain marine fossils of Colorado age.	2,300	Chiefly gray to olive sandstone; some beds of dark-gray to green shale. Top removed by erosion.	1,000+
		Fissile black shale.	500-650	Fissile black shale.	500
Cretaceous (Lower Cretaceous).	Kootenai formation.	Unconformity		Unconformity	
		Chiefly purple and maroon shale. Several interbedded layers of gray to green and maroon sandstone and thin beds of limestone. The lower limestones weather buff. The uppermost is crowded with small fresh-water gastropods.	1,350	Red and green shales and flaggy sandstones. Pebbly bed at bottom. Several thin bands of limestone. Those in lower portion weather buff. The uppermost is crowded with small fresh-water gastropods.	1,500
Jurassic.	Ellis formation.	Unconformity?		Unconformity?	
		Chiefly buff-weathering limy shale. Near the middle a layer of cross-bedded gray sandstone 100 feet or more thick. Thin beds of limestone in lower part contain marine Jurassic fossils.	400-650	Chiefly gray to green shale and sandstone. Buff or yellow on weathered surface. Thin beds of limestone in lower part contain marine Jurassic fossils.	430
Carboniferous.	Permian?	Unconformity		Unconformity	
		Chert, cherty quartzite, gray sandstone, and limy shale. Varies in thickness and composition from place to place. A bed of rock phosphate at bottom.	50-300	Gray, somewhat cherty quartzite; weathers rusty brown. A little shale interbedded.	120
	Pennsylvanian?			Chiefly gray cherty limestone. Marine Pennsylvanian or Permian fossils. A bed of rock phosphate in lower part.	90
		Quadrant quartzite.	200-300	Massive fine-grained quartzite, white to pale drab, stained yellowish-brown.	220-350
	Mississippian.	Light to brownish gray quartzite, pure. Rusty brown on weathered surface.	250	Unconformity?	
		Deep-red shale and impure limestone. Shale commonly mottled with light-colored spots.		Maroon shale, commonly mottled, and gray to pink magnesian limestone.	100-300
Devonian.	Jefferson limestone.	Unconformity?		Unconformity?	
		Limestone, massive and light gray to blue in upper part, thin bedded and dark gray in lower; fossiliferous.	1,500	Limestone, massive, white to pale gray in upper part; lower part thin bedded, flaggy, black, weathering light blue; fossiliferous.	1,200-1,500
		Unconformity?		Unconformity?	
		Chiefly light-gray to black limestone; fossiliferous.	700	Light-gray to black magnesian limestone; fossiliferous.	1,000

Generalized sections of pre-Tertiary sedimentary rocks in the Garnet and Flint Creek ranges, Mont.—Continued.

Geologic age.		Formation.	Garnet Range.		Flint Creek Range.	
			Character.	Thickness (feet.)	Character.	Thickness (feet.).
Cambrian.	Silurian?	Maywood formation.	Thin-bedded gray limestone. In places streaked and mottled with pink and yellow.	600±	Magnesian reddish, gray, and whitish limestone and gray and green shale.	200-300
		Red Lion formation.			Unconformity?	
		Hasmark formation.			Laminated siliceous white to drab and purple limestone and black to olive-green calcareous shale.	300
		Silver Hill formation.			Magnesian white to blue-gray limestone and calcareous shale.	1,000
		Flathead quartzite.			Brown, white, and green banded calcareous shale, siliceous laminated limestone and dark-green shale.	330±
Algonkian.			Unconformity		Vitreous gray to drab quartzite.	150
			Shale and sandstone, chiefly red. Bottom not exposed.	1,000+	Unconformity	
	Belt.				Shale and sandstone, chiefly red.	5,000
					Thin-bedded siliceous and ferruginous limestone and shale, generally buff on weathered surface. (The underlying formations exposed in other parts of the Phillipsburg quadrangle are not present in the Flint Creek Range.)	4,000±

The absence of the Flathead quartzite, the Silver Hill formation, and the Hasmark formation from the Garnet Range, as shown by the section, is thought to be due to a delayed submergence of that area beneath the Cambrian sea. This interpretation, however, is based on a single observation on the divide between Hoover and Chimney creeks, where a limestone thought to be the equivalent of the Red Lion directly overlies Algonkian shale. It should therefore be considered as possibly to be modified in the light of future investigations.

Exclusive of the Algonkian rocks, whose association with the bed of rock phosphate under consideration is very remote, both sections, viewed broadly, show a gradual progressive change in composition from bottom to top. In a general way they may be divided into a lower, an intermediate, and an upper group, in which limestone, shale, and sandstone, respectively, are the predominant kinds of rock. The lower group may be taken as comprising all the strata

below the Quadrant (?) quartzite, the intermediate group those from the Quadrant (?) quartzite to the black Colorado shale, inclusive, and the upper group those above that shale. Except the relatively thin Flathead quartzite, which is present only in the Flint Creek Range section, the lower group consists almost exclusively of limestone. The intermediate group is composed of alternate layers of limestone, shale, and sandstone, of which, however, the shale forms more than half. The phosphate bed occurs in the lower part of this group. The upper or sandstone group contains several beds of shale but is practically free from limestone.

In the Garnet Range the rocks have a generally regular distribution. The limestone group largely occupies the summit area and the shale group the south slopes. The adjacent valley is underlain by the sandstone group, which, however, is concealed in many places, by Tertiary and later deposits.

The distribution of the rocks in the Flint Creek Range is difficult to characterize in general terms. The rocks of the sandstone and shale groups are most abundant toward the north, but all the formations are irregularly and more or less widely distributed.

In general, the three main groups described give rise to distinctive surface features. The limestone group forms cliffs and crags which, because of their prevailing light color, may be seen and recognized for long distances. Because of the different degrees of hardness of its beds the shale group is characterized by ridges and hollows. Except locally, where hardened by contact with igneous rocks, as in the foothille east of Hoover Creek, the sandstone group is marked by rather low and smooth surfaces.

As the phosphate bed nowhere crops out prominently, its location must usually be determined by reference to outcrops of the adjacent rocks. In the following paragraphs the formations most useful for this purpose are described and the stratigraphic distances of the phosphate bed above or below them are given. Where the regular sequence of the rocks has not been disturbed, the stratigraphic distance is a factor of general application for locating the probable position of a concealed bed with reference to an exposed one. It is the vertical distance between the given beds considered as occupying the regular order and horizontal position in which they were laid down, or, in other words, the distance measured along a line perpendicular to the planes of stratification, which are generally upturned in this region.

MADISON LIMESTONE.

The Madison limestone is a remarkably persistent formation throughout the western phosphate field. In the Garrison field the phosphate bed or its equivalent lies from 450 to 550 feet, and in the

Philipsburg field from 350 to 650 feet stratigraphically above it. Because of its habit of forming conspicuous light-colored cliffs and crags, the Madison is easily recognized and generally well known. Although some of the other limestones are prominent in places, none is comparable in extent and massiveness with the Madison or is likely on close inspection to be mistaken for it. The upper and more massive portion of the Madison limestone commonly contains irregular bodies of gray chert, some of which are very large. In places its outcrops are superficially stained red with ocher derived from the overlying red beds of the Quadrant (?) quartzite. The Madison generally contains abundant fossils of Mississippian age, of which a cone-shaped coral is especially useful for identifying the formation in the field. In a specimen broken so as to show a cross section this fossil appears as a little wheel about an inch in diameter with the hub a little off the center.

In the Garrison field the Madison limestone is practically confined to the summits of the Garnet Range, along which it forms a broad, irregular but almost continuous belt. Its most prominent outcrops are in Saddle and Hogback mountains and the cliffs and crags along some of the canyons, notably that of Warm Spring Creek.

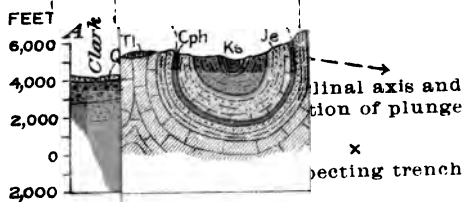
The occurrence of the several formations in the greater part of the Philipsburg field is shown in detail by the geologic map of the Philipsburg quadrangle.¹ In this area the Madison limestone is widely distributed, and some of its most prominent outcrops are along the canyons of Boulder and Flint creeks above Maxville.

QUADRANT (?) QUARTZITE.

The Quadrant formation as described in the Philipsburg folio lies next above the Madison and consists of a shale member above which are two beds of quartzite separated by several feet of impure limestone. The beds above the lower quartzite are believed to be equivalent to the Phosphoria formation of southeastern Idaho and are described on pages 207-211 under the name Phosphoria, only the lower quartzite and the underlying shale being included here under the term Quadrant (?) quartzite. In the eastern part of the Garrison field the phosphate bed lies directly upon the quartzite. At Philipsburg the two are separated by about 30 feet of impure limestone. The shale member does not crop out prominently. It is generally red in color and commonly marked with large oval spots of pale green or yellow. In places considerable red ocher that has resulted

¹ Calkins, F. C., and Emmons, W. H., U. S. Geol. Survey Geol. Atlas, Philipsburg folio (No. 196), 1915.

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PHOSPHATE

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from the weathering of this stratum has imparted a conspicuous color to the soil or stained the underlying Madison.

Because of its prominent outcrops and close association with the phosphate bed, the quartzite member is particularly valuable as a guide to the location of the phosphate. It commonly forms bold reefs and knobs of a grayish-yellow or light reddish-brown color and is inclined to be massive and blocky. It is mostly fine grained and vitreous, is light gray on fresh fracture, and in places has a cherty appearance in the upper part. It is not unlike the Flathead quartzite, and the two may be confused unless some of the adjoining strata are present in regular sequence to aid in the differentiation.

From the southeast end of the Garnet Range westward to Drummond and beyond the Quadrant quartzite forms a sinuous belt parallel to that of the adjoining Phosphoria formation (see Pl. VIII) and commonly situated near the top of the main slope. Its outcrops are especially prominent in the canyons of Warm Spring, East Brock, and Brock creeks, where blocky talus has accumulated below them. It also forms a conspicuous wall that curves around the southeast shoulder of Saddle Mountain and a knob near the center of T. 10 N., R. 9 W., northeast of Garrison, in which the rock is brecciated by faults.

In the Philipsburg field the Quadrant (?) quartzite forms the summits of the knobs near Philipsburg known as Flagstaff Hill and Red Hill and the long north-south reefs that cross the basins of Boulder, Gird, and Douglas creeks, as well as many prominent features elsewhere.

The Quadrant (?) quartzite has not been recognized in the southern part of the western phosphate region. Formations probably equivalent to it in part are the Weber quartzite and Morgan formation in Utah and the Wells formation in Idaho.

PHOSPHORIA FORMATION.

In southeastern Idaho and adjacent regions the phosphatic shales and cherty beds at the top of the Paleozoic section are known as the Phosphoria formation. In that region the Phosphoria is composed of an upper cherty member and a lower shale member that is highly phosphatic, and some of the beds contain abundant fossils of Pennsylvanian or Permian species. As a rule there is a bed of high-grade rock phosphate at or very near the bottom. The Phosphoria overlies a thick accumulation of sediments, chiefly sandstone or quartzite, of Pennsylvanian age, known as the Wells formation, which in turn rests upon a limestone of upper Mississippian age that overlies the Madison limestone. No angular discordance between the

Phosphoria and the Wells has been observed, but the Wells appears to have been eroded in places before the Phosphoria was deposited. In Montana, at Melrose¹ and Elliston,² as well as in the area under consideration, the phosphate-bearing formation, although generally thinner, has a similar composition and apparently the same stratigraphic position, and the application of the name Phosphoria in Montana is therefore believed to be warranted.

The character of the Phosphoria formation is shown by the following sections from the Garrison, Philipsburg, and Melrose fields, Mont., together with one from southeastern Idaho, where the formation attains its greatest development.

¹ Gale, H. S., Rock phosphate near Melrose, Mont.: U. S. Geol. Survey Bull. 470, pp. 440-451, 1911.

² Stone, R. W., and Bonine, C. A., The Elliston phosphate field, Mont.: U. S. Geol. Survey Bull. 580, pp. 373-383, 1913.

Sections of Phosphoria formation in Montana and Idaho.

Garrison field, Mont.		Philipsburg field, Mont.: Flagstaff Hill.	Melrose, Mont. ^a	Southeastern Idaho: Georgetown Canyon and vicinity. ^b
West of Drummond.	Warm Spring Creek north of Garrison.			
Limestones, shale, and sandstone of Ellis formation (Jurassic). Unconformity?	Limestone, shale, and sandstone of Ellis formation (Jurassic). Unconformity?	Limestone and shale of Ellis formation (Jurassic).	Shale and limestone (Triassic? or Jurassic?).	Yellow to green shale (Woodside shale, Lower Triassic).
Feet. Grayish chert.....0-100 Drab shale, slightly phosphatic.....20± Brown sandstone containing scattered nodules of rock phosphate.....11	Feet. Yellow to gray chert.....35 Gray to brown chert, phosphatic, with a 4-foot bed of rock phosphate at bottom.....18	Feet. Yellowish-brown sandstone and quartzite.....130 Red to brown shale.....20 Yellowish-brown sandstone and shale; phosphatic; several thin beds of rock phosphate at bottom.....30	Feet. Chert (and quartzite?)....105 Stratum of phosphatic shale and bed of rock phosphate at bottom.	Feet. Purple to brown chert, cherty limestone, and shale.....240-550 Phosphatic shales, with some thin beds of feld limestone and several beds of rock phosphate..83-193
Unconformity? Sandstone, limestone, and quartzite (Quadrant? quartzite).	Unconformity? Reddish-weathering quartzite; cherty at top (Quadrant?).	Cherty limestone and pure quartzite (Quadrant?).	Cherty limestone, sandstone, quartzite, and shale (Quadrant?).	Unconformity? Sandy limestones and quartzites (Wells formation).
131±	53	180	105	500±

^a U. S. Geol. Survey Bull. 470, pp. 444-446, 1911.^b U. S. Geol. Survey Bull. 577, pp. 22-23, 1914.

The character and composition of the Phosphoria formation vary somewhat within the Garrison and Philipsburg fields. Between Garrison and Drummond the lower member loses much of its phosphate and becomes predominantly sandy, and both members increase in average thickness but show notable irregularities in that respect. Between the Garnet Range and Philipsburg the upper member changes from a cherty-appearing rock to one that is apparently nothing but sandstone. A specimen of what appeared to be chert, from the Warm Spring Creek section, proved on microscopic examination to be an extremely fine grained quartz sandstone with an abundant siliceous cement.

In the portion of the Garrison field lying west of Hoover Creek the Phosphoria formation, although fairly persistent, contains no phosphate deposits of present economic importance. The equivalent of the phosphate bed is a stratum of fine, soft yellowish-gray sandstone of varying thickness, weathered portions of which are characterized by pale-pink and brown bands.

The base of the Phosphoria is well defined in the Garrison field, where the phosphatic portion rests directly upon the Quadrant (?) quartzite. At Philipsburg, however, some limestone, whose relationship is in doubt, separates the phosphatic stratum from the quartzite (the lower quartzite of the Quadrant of the Philipsburg folio). This limestone is tentatively included with the Quadrant.

The known distribution of the Phosphoria formation, which is practically the same as that of the lands underlain by workable deposits of rock phosphate (see Pl. IX), ranges over an area of about 100,000 square miles that extends from western Montana into northern Utah and central Wyoming. The formation is most abundantly developed in the south-central part of this region, between which and the much smaller areas of the formation in Montana there is a considerable gap. There is reason to believe, however, that future explorations will show the Phosphoria to be present in parts of the intervening area also.

In the Garrison field the Phosphoria (see Pl. VIII) forms a narrow band that winds in and out along the southerly slopes of the Garnet Range. The portion of this band that is of greatest value with regard to the occurrence of rock phosphate forms a large loop that curves around the southeast end of the range north of Garrison, and lies for the most part near the summit of the main slope at an altitude of about 6,500 feet. To the west of this loop are several smaller but generally parallel curves that in places carry the formation down to the valley level (4,500 feet).

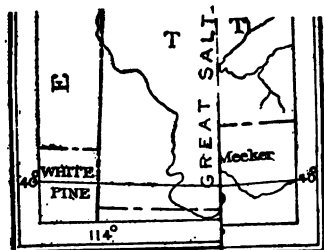
In the Philipsburg field the Phosphoria, if it is everywhere present in the upper part of the Quadrant formation as mapped in the Philipsburg folio, has a wide distribution but is most abundantly

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developed to the north of Philipsburg. It forms several long north-south bands and loops which cross the basins of Boulder, Gird, and Douglas creeks, and some of which extend northward beyond the limits of the Philipsburg quadrangle.

The shale and phosphate member of the Phosphoria does not crop out prominently. Its position is commonly marked by a slight depression in which much soil and rock débris have accumulated.

The cherty member in places forms knobs and reefs, of which the outcrop on the west slope of Flagstaff Hill at Philipsburg is an example, but it is generally much less conspicuous than the Quadrant quartzite.

ELLIS FORMATION.

Although Triassic strata occupy large areas in southeastern Idaho, they are absent in the localities under consideration, where the Phosphoria is overlain without angular discordance by the Jurassic Ellis formation. In the Garrison field a prominently outcropping bed of gray sandstone lies near the middle of the Ellis, about 300 feet above the phosphate bed. It is easily recognized by a cross-bedded structure that is generally emphasized on the weathered surface by rusty streaks. The rock is further distinguished by conspicuous grains of black scattered through the gray. It contains a thin pebbly bed near the bottom and is disrupted by weathering into blocky flagstones and coarse fragments that clutter the surface near its outcrop. In places, as near the summit of the main slopes of the Garnet Range east of Brock Creek, it forms prominent reefs. In the Philipsburg field an equivalent stratum is moderately conspicuous in the basin of Gird Creek, where it lies between 300 and 400 feet above the phosphate bed.

KOOTENAI FORMATION.

Although the outcrops of the Kootenai formation are generally subdued, it can ordinarily be recognized in the Garrison and Philipsburg fields by its predominant red, purple, and maroon colors. It contains two rather prominent beds of limestone, each from 30 to 100 feet or more in thickness. The lower limestone is about 1,150 feet above the phosphate bed, is pale yellow on the weathered surface, and shows rather conspicuously small bodies that branch like twigs. In places this stratum is split into two layers by 100 feet or so of shaly beds. The upper limestone is about 1,800 feet above the phosphate bed, is light gray to blue on the weathered surface, and is crowded with fossils of small fresh-water snails. Two or three layers in this stratum generally crop out as narrow but prominent reefs and walls, as shown, for example, on the hill immediately back of Drummond.

Next above this limestone and forming the topmost stratum of the Koótenai is a 100-foot bed of sandstone and shale. It is generally inconspicuous, but in the Garnet Range from Brock Creek east it has been partly transformed to a quartzite that forms prominent reefs and knobs. In appearance these are not unlike outcrops of the Quadrant (?) quartzite except that they are narrower and in places their bedding planes are ripple marked.

TERTIARY AND LATER ROCKS.

Several formations which are confined practically to the main valleys and whose relations to the phosphatic stratum are accidental are not included in the tabular sections but were described more particularly in a former report.¹ They consist of sands, clays, and marls of late Tertiary age that underlie the bench lands, gravels that cover them, and the more recent alluvium of the stream flood plains or bottom lands.

Igneous rocks which in many places are found in close proximity to the phosphatic stratum but whose relations to it are purely accidental occur in both the Garnet and Flint Creek ranges. Those of the Garnet Range are chiefly lavas that were spread over the surface from time to time. Those of the Flint Creek Range are chiefly granites (in the more common significance of that term)—rocks that, in a fluid condition, came up from unknown depths and either forced aside the strata or engulfed them. For the most part the granites are confined to the central and higher portions of the range. In the Garnet Range east of Drummond the only rocks similar in origin and texture to the granites are some dense, heavy dark grayish-green crystalline rocks (gabbros) that occur in sheetlike masses or sills wedged in between beds of the sandstone group (Colorado). Microscopic examination of a coarsely granular specimen from the outcrop of a sill 400 feet thick that occurs in the Colorado formation about 1,550 feet above its base east of Hoover Creek shows it to contain augite, hypersthene, olivine, biotite, and feldspar, of which the ferromagnesian minerals predominate. About 30 per cent of the feldspar is orthoclase, the remainder being calcic labradorite. The principal outcrops of these rocks are in the foothills east of Hoover Creek, half a mile west of the mouth of Brock Creek, and along Little Blackfoot River 8 or 10 miles east of Garrison. No outcrop, however, lies within several thousand feet stratigraphically of the phosphate bed.

Several patches of andesitic lava, remnants of fairly extensive flows, occur in the Garnet Range, mainly on the summit and northern slopes. The predominant variety of this rock forms the summit of

¹ Pardee, J. T., Coal in the Tertiary lake beds of southwestern Montana: U. S. Geol. Survey Bull. 531, pp. 232-236, 1913.

Mount Baldy, and in a part of the area between that point and the head of Hoover Creek overlies and conceals the outcrop of the phosphatic stratum. A specimen from the summit of Mount Baldy is a dense gray cryptocrystalline rock with a platy structure. Under the microscope it shows augite and altered hypersthene in a fine-grained groundmass practically devoid of phenocrysts, also some plagioclase and glass and accessory iron ore. The exposures of the andesitic rock appear grayish or purplish brown and are commonly broken by very numerous joints into thin plates or, less commonly, into small fragments shaped like distorted rhombs. Here and there are small patches of other lavas, some of which have the composition of basalt and some of rhyolite.

STRUCTURE.

FOLDS.

Except the Tertiary and later strata, which are but slightly folded, the bedded rocks of the areas under consideration are in general steeply tilted. The Garrison field is dominated by a series of parallel folds, the axes of which have a general southeasterly direction and incline downward to the southeast. Erosion has worn away the upper portions of the ridges (anticlines) and exposed the upturned edges of certain beds, including the Phosphoria formation, which wind back and forth along the south slope of the Garnet Range. (See Pl. VIII.) The largest individual fold is a broad arch, the Garrison anticline (Pl. VIII, section *A-A*), that occupies the area east of Brock Creek and causes the trace of the Phosphoria formation to form a loop open to the northwest. On the flanks of this anticline the beds are inclined 40° to 65° from the horizontal, and around its southeast end 20° to 40° . The smaller folds that occupy the area from the Garrison anticline westward to Drummond and beyond are tightly compressed (Pl. VIII, section *B-B*), and the rocks involved in these folds therefore show very steep dips, vertical attitudes being not uncommon, and the outcrops form a series of narrow pointed loops.

The rocks of the Philipsburg field have been folded even more severely than those of the Garnet Range, and the beds therefore dip steeply nearly everywhere. Not uncommonly they are overturned, lying one above another in reverse order. Within the Philipsburg quadrangle the general direction of the folds is a little east of north, and the pitch is northward. Within a distance of 5 or 6 miles north of the quadrangle the structural axes bend to a general northwesterly direction parallel to those of the Garnet Range. A detailed description of the structure in the Philipsburg quadrangle is given in the report by Emmons and Calkins.¹

¹ Emmons, W. H., and Calkins, F. C., *Geology and ore deposits of the Philipsburg quadrangle, Mont.*: U. S. Geol. Survey Prof. Paper 78, 1918.

Considered in general terms as to their structure, the Garnet Range and, less plainly, the Flint Creek Range, are anticlinal, and the intervening valley of Clark Fork is a broad compound syncline.

FAULTS.

In the Garnet Range faults are of no great structural importance. So far as observed, they are most conspicuous in the southeast end of the Garrison anticline, which is crossed transversely by several parallel fractures. These dip steeply northwest, and on each the block to the northwest has dropped slightly. The displacements are shown by jogs that slightly narrow the loop formed by outcrops of the Phosphoria formation (Pl. VIII). A zone of faults that have caused slight dislocations extends from Drummond northeastward to Hogback Mountain. Elsewhere, although small faults are doubtless present, none were observed. The position of most of the faults observed is marked by masses of crushed recemented rock or breccia, especially where the faults cross the Quadrant (?) quartzite.

In the Philipsburg field, on the other hand, faults are numerous, and the dislocations many of them have caused are so extensive that beds far removed from each other in the normal sequence are made to adjoin. Both normal and thrust faults occur, and the general direction of the larger ones is north or northeast, parallel to that of the folds. In many places faults, as shown by the Philipsburg folio, follow closely the trend of the areal exposures of the Quadrant (?) quartzite, a fact which allows the possibility that in places the Phosphoria may have been cut away.

GEOLOGIC HISTORY.

With respect to the main geologic events in the Garrison-Philipsburg area, the vast amount of time that has elapsed since the deposition of the Algonkian rocks may be divided into two periods of strongly contrasting conditions. In comparative terms the earlier period was a time of monotonous quiet dominated by sedimentation; the later period one of vigorous mountain building and erosion.

During the earlier and longer period, which includes Paleozoic and all but the latest part of Mesozoic time, the surface was generally low; sometimes it was slightly above sea level, but more commonly it was submerged and receiving the sediments derived from the surrounding more or less distant lands. The period began with the advance of the sea from south to north over a surface of moderate relief eroded in the top of the Algonkian shale. Its earliest record is that afforded by the Flathead quartzite, a formation which is composed chiefly of beach sands, and whose absence from the

Garnet Range is interpreted to mean that the sea had not yet overspread that area. Soon, however, the region was entirely submerged by a practically clear sea, in which the great group of limestone beds ending with the Madison (lower Mississippian) was laid down. For a time deposition ceased, probably because the surface was elevated to or above sea level, but the process recommenced at the beginning of the Pennsylvanian epoch. The fact that sands and muds were brought in at this time shows that the land was either nearer than before or was being more vigorously eroded. The red color of the mud that formed the lower member of the Quadrant (?) quartzite is generally believed to indicate absence of vegetation and therefore an arid climate in the lands that were being eroded.

After the sands composing the Quadrant (?) quartzite, whose purity indicates that they were derived from a sea beach, were laid down, a change in the conditions, not yet well understood, permitted the precipitation of highly phosphatic material. During this epoch the water was at times more or less muddy over most of the general phosphate field, as shown by the shales that are interbedded with the rock phosphate. In the Garrison field the shale and rock phosphate give place to fine sandstone toward the northwest, showing that a beach existed not far away in that direction. Whether the beach was the mainland or merely an island is not known positively, but the absence of phosphatic rocks west of this locality supports the view that it was a point on the western mainland shore of the Phosphoria sea. For a considerable time afterward, represented in southeastern Idaho and adjacent regions by thick strata of Triassic age, no sediments were deposited in the Garrison and Philipsburg fields, or if any did accumulate, they were subsequently washed away. Presumably the surface was above sea during this interval, but not far enough above to be deeply channeled by streams.

The sea or a shallow arm of it again occupied this area during most of Jurassic time and part of Cretaceous time. The late Mesozoic deposits show, however, that marine conditions were in general gradually replaced by those characteristic of fresh-water and land areas, which became permanent in later Cretaceous time. Altogether during the period of quiet sedimentation about 13,000 feet of material accumulated in practically horizontal beds, the upper two-thirds of which overlay the phosphate deposit. That in places the phosphate bed is uncovered at present is due to the general deformation and erosion that occurred in the succeeding period.

The later period began with a mountain-building epoch that probably included parts of both late Cretaceous and early Tertiary time. In this epoch, evidently through the agency of great pressure, the hitherto flat-lying strata were severely folded, elevated, and in places broken and piled upon one another. In the area of the Garnet Range

the axes of the folds assumed the average northwesterly direction of the Rocky Mountain structure, but in the Flint Creek Range they were turned to a rather exceptional course of north-northeast. In the latter area, in addition to being tightly folded, the beds were extensively dislocated by faults and invaded from below by large masses of granite. The Garnet and Flint Creek Range areas were dominated by anticlines and the intervening area of Clark Fork valley by a syncline. In general, therefore, the mountains and lowlands of this early epoch appear to have coincided in position with those of to-day.

As the anticlinal ridges were gradually worn down by erosion the upturned and hitherto concealed strata were exposed at the surface. Although erosion must have been active from the time the land first became elevated, it evidently was at first unable to reduce the mountains as rapidly as they grew. Later, however, the mountain-building forces apparently died out, and before the Tertiary period was well advanced erosion had become the dominant process.

During the epoch of erosion, which continued until about the middle of Tertiary time, the general region was worn down to a low surface, in general of but little relief. Doubtless the sites of the former mountains, at least of the ancient Flint Creek Range, were marked by moderate elevations, and there is reason to believe that to the west of Drummond the ancient Clark Fork followed essentially its present course.

During the succeeding and final epoch the surface was generally reelevated several thousand feet and the canyons and valleys of to-day were formed. This epoch was also characterized by lava flows and by the accumulation in the principal valleys, which at times held lakes, of thick sediments, composed largely of volcanic sand.

Clearly the canyons of this area were cut by the streams that occupy them, but no hypothesis based on erosion alone is sufficient to explain the origin of the broad, more or less inclosed basins of which the Clark Fork and Flint Creek valley is an example. Although their histories have not been fully interpreted, there is strong evidence, particularly the deformation of the lake beds, in support of the view that these basins are due chiefly to warping of the surface, aided by dislocation along faults.

This latest epoch was relatively short compared to any of the other periods into which, for convenience, the geologic history of this region has been divided. Its length was so great, however, as to be difficult of conception by the human mind. From the work done by the streams in excavating their canyons—for example, those sunk in the hard rocks of the Flint Creek Range—geologists estimate the length of this epoch (from Oligocene time to the present) as more than 1,000,000 years.

PHOSPHATE DEPOSITS.

GENERAL DISTRIBUTION AND CHARACTER IN THE WESTERN REGION.

In the western region rock phosphate occurs at two horizons in the Paleozoic section—at the top of the Madison limestone and in the Phosphoria formation. The bed at the top of the Madison is, locally, at least, of workable dimensions,¹ but its extent and value outside of certain localities in northern Utah are not yet known. All other known phosphate deposits in the western region, including those described in the present report, occur in the Phosphoria formation or its equivalents.

Deposits of rock phosphate occurring in the Phosphoria formation or its equivalents are irregularly distributed over an area of about 100,000 square miles, commonly known as the western phosphate region, that includes adjoining portions of Montana, Idaho, Wyoming, and Utah. Plate IX shows the location of the known deposits that are regarded as of economic importance, the shaded areas being those so far classified by the Geological Survey as phosphate lands. According to the definition adopted, phosphate lands must be underlain (except under certain conditions of uncommon occurrence in the western region) by a bed of rock phosphate 1 foot or more in thickness, which contains 30 per cent or more of tricalcium phosphate and which lies within depth limits that range, as the other factors increase, from 0 to 5,000 feet vertically below the surface. The northwesternmost of these deposits are those of the Garrison and Philipsburg fields. The relatively small area of these fields, however, does not mean that their deposits are of unimportant volume; on the contrary, it draws attention to the enormous magnitude of the deposits as a whole.

That the phosphate region extends northward far beyond the latitude of Garrison is suggested by a recent discovery of rock phosphate on an east-west section passing through Banff, Alberta.²

Throughout the western region the rock phosphate of the Phosphoria formation occurs as a sedimentary or bedded deposit associated with cherty rocks and shales. As a rule it is somewhat softer than limestone but is noticeably heavier than ordinary sedimentary rocks, its average specific gravity being about 2.9. It is further characterized by an oolitic texture (composed of small round grains that suggest fish roe) and a thin bluish-white coating developed on

¹ Finch, E. H., Rock phosphate of Mississippian age in northern Utah: U. S. Geol. Survey Bull. — (in preparation).

² Adams, F. D., and Dick, W. J., On the extension of the Montana phosphate deposits northward into Canada (paper presented at the twenty-eighth annual meeting of the Geological Society of America, Washington, D. C., December, 1915).

weathered surfaces. When freshly broken it has a fetid odor, and the fractures produced, if the specimens are undecomposed, generally cut through the grains instead of passing around them.

The phosphate beds exhibit a considerable range in purity and thickness, but most of those mapped are from 3 to 8 feet or more in thickness and contain 60 per cent or more of tricalcium phosphate. Ordinarily the chief impurity present in the deposits is fine quartz sand, together with small amounts of other substances, including bituminous matter.

The mineral composition of the rock is not definitely known. The phosphorus is undoubtedly combined with lime, and as analyses of the purest material obtainable show the proportions represented by the formula of tricalcium phosphate, $\text{Ca}_3(\text{PO}_4)_2$, that substance is assumed to be present, although it has not been identified in crystal form.

Although the phosphate beds vary in thickness and composition from place to place, their irregularities are not to be compared with those of metalliferous lodes. They are rather to be estimated like beds of coal or limestone, of which measurements and samples at intervals of a mile or more suffice for a general average. In the western region as a whole the phosphate beds are inclined, and commonly the dip is sufficiently steep to indicate that overhead stoping would be the most suitable method of mining. Because some of the more soluble impurities have been leached out, samples of float (loose fragments that have become detached and transported by natural agencies to greater or less distances from the bed) or of superficial portions of the bed may contain 4 or 5 per cent more phosphorus pentoxide than those from underlying portions. As the deposits have not been explored beyond depths of a few feet the actual composition of their deeper portions is unknown, but on well-substantiated theoretical grounds the phosphorus pentoxide is believed to show no further essential diminution with depth.

EASTERN PART OF THE GARRISON FIELD.

DISTRIBUTION AND OCCURRENCE.

In the Garrison field the economically important portion of the phosphate deposit is confined to the area east of Hoover Creek. West of that stream the phosphatic stratum, although fairly persistent, is of low grade. The distribution and attitude of the phosphate bed east of Hoover Creek are controlled by the Garrison anticline, a large fold that has a northwesterly course and pitches southeast. The trace of the bed, which is practically equivalent to that of the Phosphoria formation, as shown by the map (Pl. VIII), is a narrow band, 18 miles or more in length, in the form of a huge

fishhook so placed that the southeast end of the Garnet Range lies within the curve. Except where it is lowered by erosion 1,500 feet or more in the canyons of Warm Spring, Brock, and East Brock creeks, the band lies near the summit of the main slope, at a general altitude of 6,500 feet.

Along this course the dip of the phosphate bed ranges from 30° to 65° and with respect to the mountain mass is outward, or in the same direction as the general slope of the surface. Thus from Hoover Creek to Warm Spring Creek, a distance of 10 miles, the strike is southeast and the dip southwest. Beyond Warm Spring Creek, as the bed rounds the end of the range, the strike gradually changes, at first to the east, then to the north, and finally to the northwest, and the direction of the dip changes correspondingly.

Adjoining the Garrison anticline on the southwest is a corresponding downfold that at the deepest portion has carried the phosphate bed to a depth of about 10,000 feet below the present surface. Farther southwest, in the foothills of the Flint Creek Range, north of Boulder Creek, the deposit is reelevated to the surface by other folds. To the east of the Garrison arch the phosphate bed is again depressed and covered by a thick overburden of Tertiary rocks, but it reappears at the surface in the vicinity of Elliston.

As a rule the position of the phosphate bed is marked by a shallow soil-covered trench in which loose fragments of rock phosphate (float) are more or less abundant and, because of their light-colored superficial coating, generally conspicuous.

For the most part the rock phosphate of the area under consideration does not differ in appearance from the general type as described in a former paragraph. The grains vary slightly in size but average about 1 millimeter in diameter, which is about equivalent to that of a small pin head. The rock is predominantly black but in a few places has a pink shade, owing to a little iron oxide in the matrix, or is brown and rather soft, apparently because of decomposition.

The general absence of large pieces of float is due to the fact that the rock has a pronounced fissility parallel to the bedding and numerous joints at right angles to the fissility, along which it splits into blocks and slabs, few of them larger than an ordinary brick.

The only natural exposure of the rock phosphate seen covers a small area on the steep slope west of East Brock Creek, but in a few other places the soil cover is very thin. Additional exposures were made by digging trenches on Warm Spring Creek near the center of T. 10 N., R. 9 W., and at other points as indicated on the map (Pl. VIII).

Above and below the phosphate bed are layers of gray to yellow, red, or brown fine-grained brittle rocks that have the appearance of

chert. A foot or two of the lower layer and exceptionally as much as 15 feet of the upper layer are noticeably phosphatic. For the most part, as indicated by variations in the bluish-white coating, the phosphatic substance is very finely divided and irregularly distributed through the rock. In places it is segregated in small round black grains that are scattered sparsely through the rock and form tiny but conspicuous white spots on weathered surfaces. Microscopic examination of the phosphatic chert from the exposure on East Brock Creek shows it to be composed of extremely fine quartz sand, with an abundant siliceous cement. Some of the inclosed phosphate granules have an angular fragment of quartz as a nucleus around which the phosphatic material is gathered in concentric layers.

Along a course of 12 miles east of Brock Creek prospect trenches were made at three points (see Pl. VIII), at each of which the phosphate deposit has a thickness of 4 feet or more. As the distribution of float between these exposures is fully as abundant as near them, it is believed safe to assume 4 feet as the average thickness of the bed throughout. At Hoover Creek, however, 6 miles northwest of the East Brock Creek exposure, the phosphate bed is but 1 foot thick. Whether the decrease of 3 feet is distributed over a large or a small part of this distance, in which there are no exposures, is problematic, but the abundance of the float indicates that the width is not noticeably diminished within a mile to the northwest of East Brock Creek.

COMPOSITION.

Analyses of the phosphate bed at three exposures east of Brock Creek are given below:

Analyses of phosphate bed in southeastern part of the Garnet Range, Mont.

[R. K. Bailey, analyst.]

Locality.	Thickness.	P ₂ O ₅ (phosphoric anhydride).	Equivalent to Ca ₃ (PO ₄) ₂ (tricalcium phosphate).
	<i>Ft. in.</i>	<i>Per cent.</i>	<i>Per cent.</i>
East Brock Creek.....	4 0	35.10	76.6
Warm Spring Creek.....	4 3	30.16	65.8
8 miles northeast of Garrison, near center of T. 10 N., R. 9 W....	4 0	30.98	67.6

The relatively high phosphatic content of the sample from East Brock Creek is apparently due to the fact that it represents a portion of the deposit directly exposed to the weather and therefore enriched by leaching. Before the other samples were collected a soil cover and some loose weathered material at the top of the bed were removed. The compact and unaltered appearance of the sample

from Warm Spring Creek, together with the fact that it represents the bed near the bottom of a geologically recent natural excavation 1,500 feet deep, lead to the conclusion that it is but little if any richer than the deeply buried portions of the deposit in general. It is believed, therefore, that an average of at least 60 per cent tricalcium phosphate may be safely assumed for the deposit throughout. In addition analyses of the overlying phosphatic chert show 14.7 per cent and 7.8 per cent of tricalcium, respectively, for layers 9 feet and 4 feet thick at Warm Spring Creek and northeast of Garrison.

The chief impurities in the rock phosphate of the area under consideration are sandy and clayey sediments, the composition of which is shown by the following analysis:

Analysis of rock phosphate from Warm Spring Creek, near Garrison, Mont.

[T. H. Rosenkranz, analyst.]

Silica (SiO_2) and insoluble matter	6.00
Alumina (Al_2O_3)	1.10
Magnesia (MgO)	.30
Water (H_2O)	1.45
Iron oxide (Fe_2O_3)	.45
Carbon dioxide (CO_2)	2.20
Lime (CaO)	46.90
Phosphorus pentoxide (P_2O_5)	32.10
(Corresponding to 70.1 per cent $\text{Ca}_3(\text{PO}_4)_2$).	
Sulphur trioxide (SO_3)	2.10
Undetermined	7.40
	100.00

On the assumption that practically all the phosphorus pentoxide is combined with lime as tricalcium phosphate, a small proportion of lime remains which is probably present as carbonate or sulphate (gypsum) in part. Qualitative tests show the undetermined portion to consist of organic matter, soda (Na_2O), and small amounts of other substances, including chlorine and fluorine. The latter two suggest the presence of the mineral apatite. The soda suggests that some partly decomposed feldspar sand is mingled with the quartz. The organic matter is probably the cause of the fetid odor that the rock yields when hammered.

AVAILABILITY AND TONNAGE.

The phosphate outcrop is everywhere considerably higher than the railways, and its distance from them ranges from 3 miles at the east end of the Garnet Range to 8 miles at Hoover Creek. The two

localities most favorable for extensive mining operations are located where the phosphate bed is crossed by Warm Spring and East Brock creeks, 5 and 6 miles, respectively, upstream from the transcontinental railways mentioned.

The route to each of these deposits leads through an easily traversed valley that has an average grade of about 100 feet to the mile.

The superficial portion of the phosphate deposit is the most valuable, because it is perhaps somewhat enriched through leaching of the soluble constituents and most readily available to mining. Beneath the outcrop east of East Brock Creek, which has a linear extent of 12 miles, there is evidently a considerable quantity of 70 per cent rock phosphate that could be mined by surface workings. Much of it can be very readily mined by adits driven on the bed where it is crossed by Warm Spring and East Brock creeks. A generalized profile (fig. 22) shows the outcrop to be notched by the streams mentioned to vertical depths of 1,500 feet or more (equivalent to about 2,000 feet on the dip slope of the bed). The quantity of rock phosphate containing 60 per cent or more of tricalcium phosphate that could be stoped above adits 5,000 feet in length, driven to the right and left on the bed at the levels of the streams mentioned, is estimated at

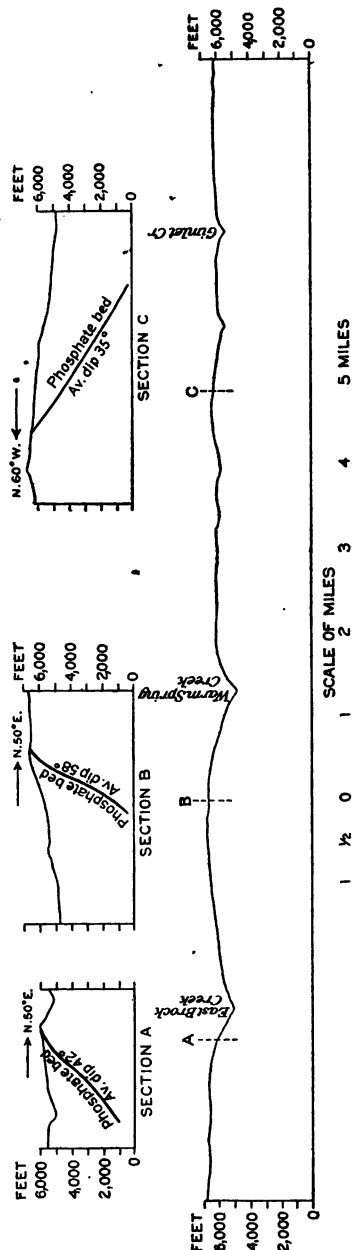


FIGURE 22.—Profile and sections along phosphate bed east of East Brock Creek, Garrison field, Mont. Lower figure is a profile of the outcrop as it would appear were its curves straightened out. The phosphate bed is really bent between the points B and C through an angle of 180°, causing the dip to change from southwest through south to northeast.

more than 6,000,000 long tons, or twice the present annual production of the United States. The estimate is based on the profile (fig. 22), the dips as given, an average thickness of 4 feet, and a

weight of 180 pounds to the cubic foot of rock phosphate. For example, the block west of Warm Spring Creek above a 5,000-foot adit has an area approximately equivalent to that of a triangle of 5,000 feet base and 1,950 feet altitude.

$$5,000 \times \frac{1,950}{2} \times 4 = 19,500,000 \text{ cubic feet} = 1,566,964 \text{ long tons.}$$

Elsewhere the deposit is in general less favorably situated for mining by adit levels, but in places it can be reached at considerable depths by crosscut tunnels of practicable lengths. The total volume of the deposit above the level of Warm Spring Creek (4,800 feet) and east of a point 1 mile northwest of East Brock Creek is estimated at more than 35,000,000 long tons. Below this block is a much greater quantity of rock phosphate, which, however, will naturally be more and more expensive to mine as depth increases. Each block representing 1,000 feet in depth (on the dip) is estimated to contain more than 20,500,000 long tons, and if 3,000 feet is assumed as the limit of profitable mining, the Garrison field contains at least 97,000,000 tons of available rock phosphate.

WESTERN PART OF THE GARRISON FIELD.

The sandstone of the Phosphoria formation in the western part of the Garrison field (see p. 210) contains sparingly and irregularly scattered bodies of rock phosphate that range in size from mere specks to nodules 1 inch in diameter, but average about a quarter of an inch. In addition, irregular cherty layers above or below the sandstone are slightly phosphatic. As a rule the phosphate nodules are relatively concentrated in a layer of the sandstone about 1 foot thick, as shown by the following sections:

Sections of phosphatic stratum in western part of Garrison field, Mont.

[W. C. Wheeler, analyst.]

Locality.	Character.	Thickness.	P ₂ O ₅ (phosphorus pentoxide).	Ca ₃ (PO ₄) ₂ (tricalcium phosphate).
		Ft. in.	Per cent.	Per cent.
Hoover Creek, sec. 13, T. 11 N., R. 11 W.	Cherty quartzite.			
	Coarsely oolitic rock phosphate. Grains $\frac{1}{2}$ to $\frac{1}{4}$ inch in diameter embedded in abundant sandy matrix.....	11 $\frac{1}{2}$	18.60	40.55
	Red chert, slightly phosphatic.....	5+		
	Quartzite.			
Burt Creek, sec. 36, T. 11 N., R. 12 W.	Sandstone, red, quartzitic.....	4+		
	Sandstone with abundant coarse grains or nodules of rock phosphate as much as 1 inch in diameter.....	7	16.29	34.51
	Similar sandstone, except that phosphate nodules are less abundant.....	1 0	2.66	5.80
	Chert.....	2 0		
	Sandstone, slightly phosphatic.....	25+		
Northwest of Drummond, sec. 23, T. 11 N., R. 13 W.	Sandstone and shale, slightly phosphatic..	15+		
	Sandstone with nodules of phosphate as much as $\frac{1}{2}$ inch in diameter.....	1 6	7.54	16.43
	Chert and sandstone, slightly phosphatic; contain fragmentary pelecypods and plants.....	4+		
	Impure limestone.			

Although the phosphate nodules are smooth and more or less spherical in form, they do not appear to be waterworn pebbles but rather are aggregates or concretions. Microscopic examination of specimens from Hoover Creek shows them to be aggregates of small round grains composed of a fibrous mineral and embedded in a sandy matrix. A thin section of a nodule from the exposure northwest of Drummond shows it to be chiefly an amorphous homogeneous mass of a reddish-black color. Distributed through the mass are a few slender crystals, 0.05 millimeter or less in length, that show interference colors of a low order and probably represent a chlorocalcium phosphate, which, however, does not have the characteristics of apatite. In addition, a few fine rounded quartz grains are scattered through the phosphatic substance and here and there appear to be partly replaced by it. Hematite, to which the reddish color is due, occurs in small irregular bodies, but no calcite was observed.

PHILIPSBURG FIELD.

In the Philipsburg field a deposit of rock phosphate of similar character to that of the eastern part of the Garrison field occurs at the same stratigraphic position. Its probable distribution in the Philipsburg quadrangle is equivalent to the distribution of the Quadrant formation, which includes the Phosphoria, as mapped in the Philipsburg folio. Accordingly, the phosphate may be expected in greater abundance north of Philipsburg, especially in the basins of Boulder, Gird, and Douglas creeks, than elsewhere. The bed is almost everywhere tilted steeply, and the relief of the surface is so varied that a large part of the deposit can be mined through adits.

As in the Garrison field, the phosphatic stratum is generally concealed by a surface mantle, and except along Gird and Douglas creeks, float phosphate is very scanty, so far as known. The character of the phosphate deposit at the two localities in which it has been exposed is shown by the following sections:

Sections of phosphate bed in northern part of Philipsburg field, Mont.

[W. C. Wheeler, analyst.]

Locality.	Character.	Thickness.	P ₂ O ₅ (phosphorus pentoxide).	Ca ₃ (PO ₄) ₂ (tricalcium phosphate).
		<i>Ft. in.</i>	<i>Per cent.</i>	<i>Per cent.</i>
Philipsburg, south slope of Flagstaff Hill.	Yellowish-brown sandstone.			
	Brown phosphate.....	6	11.85	25.8
	Brownish-yellow shale.....	4	7.05	15.37
	Hard black phosphate.....	1	31.95	69.8
	Soft clayey phosphate.....	1	22.03	48.02
	Brown to blue-gray shale.....	5	11.53	25.13
	Brown to black phosphate.....	1	22.73	49.55
	Phosphatic chert.....	2	2.29	4.99
Maxville, tunnel on property of J. D. Fields.	Dull-gray limestone.			
	Fault gouge and breccia.....	3+		
	Soft crushed black phosphate.....	3	15.20	33.13
	Brown sandstone with black shaly partings, slightly phosphatic.....	15+		

The layers that compose the phosphate deposit on Flagstaff Hill are concealed by 3 feet or more of soil and are considerably decomposed to an additional depth of 2 or 3 feet. The dip averages 55° W., and all but a moderate-sized block of the deposit at this locality lies below the natural drainage levels. At the Maxville exposure the bed stands vertically, is severely crushed, and is in part cut away by a fault, and the phosphate is somewhat mixed with foreign matter. The sample analyzed is therefore not fairly representative.

Northeast of Maxville, on the slopes adjacent to Gird and Douglas creeks, loose fragments of high-grade rock phosphate, some of which are more than 1 foot thick, are conspicuous in the surface mantle. Their composition, size, and abundance indicate that where it is not deteriorated because of faults or similar accidents the deposit is comparable in size and quality to that of the eastern part of the Garrison field.

USES.

Rock phosphate, after being subjected to certain chemical treatment, is used as a constituent of mixed fertilizers and is also, in a finely ground form, applied directly to the soil.¹ The conditions that govern the use of phosphatic fertilizers are beyond the scope of this report, but the fact that their use is highly beneficial under proper conditions is well established, and a steadily increasing demand for these fertilizers is to be expected.

The Garrison and Philipsburg fields are favorably situated for the manufacture of the chemically prepared fertilizer because of their nearness to the great smelters of western Montana, the potential sources of vast quantities of sulphuric acid, which is the principal chemical reagent used.

ORIGIN.

The western phosphate deposits are highly phosphatic shales and sandstones that accumulated on the bed of a Pennsylvanian or Permian sea. Their features and manner of occurrence both generally and in the Garrison and Philipsburg fields make it certain that practically no addition or concentration of phosphatic material has taken place since the beds were laid down. In this respect they differ from most of the known valuable deposits of rock phosphate elsewhere, which are generally regarded as due to concentration. For example, those of South Carolina and Florida have been determined to be chiefly the concentrated residues from the leaching of phosphatic limestones, as, in fact, are most of the other known

¹ Methods of manufacture of phosphatic fertilizers are described by Waggaman and Fry in U. S. Dept. Agr. Bull. 812, 1915.

phosphate deposits not related to igneous rocks. Perhaps the nearest analogue of the western phosphate beds is the Tennessee blue phosphate rock, from which, however, they differ in some important particulars. Compared with other sedimentary strata, the distinctive feature of the beds that compose the western phosphate deposits is their remarkably large content of phosphatic matter, a difference that has not been adequately explained.

Practically all sedimentary rocks contain small amounts of phosphates as original constituents. Large numbers of analyses show maximum averages of 0.08 per cent phosphoric acid in ordinary sandstones, 0.20 per cent in shales, and 0.42 per cent in limestones.¹ The mineral apatite, a minor original constituent of practically all igneous rocks and also a principal constituent of many veins, is regarded as the principal ultimate source of the phosphates. The transference of the phosphatic material from the original apatite to the sedimentary rocks is accomplished chiefly by solution and organic action, but the steps in the process are not fully understood. However, phosphates finally become dissolved in the ocean, from which, together with calcium carbonate, they are absorbed by marine organisms. When these organisms die their skeletons or shells become incorporated in the sediments accumulating at the bottom, but in general not before there has been opportunity for a partial re-solution of the calcium carbonate. The deposits thus formed are as a rule only feebly phosphatic, but they may be enriched as long as they are exposed to action of the sea water.

A process observed in the Baltic and North seas,² and doubtless effective elsewhere, consists in a re-solution, short migration, and re-precipitation of the phosphate as nodules or concretions gathered about shell fragments or other objects that serve as nuclei. As the deposits thus formed, however, do not, so far as known, contain more than 3 per cent of lime phosphate, the richness of the western phosphate beds seems to demand special conditions of which no present-day counterparts are known. It may be supposed that either from a most unusual and abundant source phosphates were rapidly supplied to the sea, or that conditions especially favorable to the solution and retention of calcium carbonate by the sea water but not hindering the ordinary precipitation of phosphate existed for a considerable time. In the opinion of the writer, the first supposition is exceedingly improbable, but the second is worth consideration as a working hypothesis. As is well known, the solution of calcium carbonate is favored by the presence of carbon dioxide (CO_2), which is retained most abundantly by water of low temperature.

¹ U. S. Geol. Survey Bull. 591, p. 23, 1915.

² Murray, John, and Hjort, Johan, *Depths of the ocean*, pp. 185 et seq., 1912.

In addition to an atmospheric source, the ocean receives carbon dioxide from organic substances that decompose at the bottom. Sea life is known to swarm in shallow basins situated in regions of variable climate. There is reason to believe that the late Carboniferous sea of the western phosphate region was of moderate depth and teemed with organisms of some sort, of which the bituminous matter in the rock phosphate is a residue. The known existence of glaciers elsewhere during this general period is believed to warrant the assumption of a variable climate, cool enough to maintain cold water in all but perhaps the superficial layers in the basin. Thus conditions unfavorable to the growth of coralline limestone or the chemical precipitation of lime are supposed to have characterized the period of phosphate deposition. Furthermore, water charged with carbon dioxide would tend to dissolve whatever limy objects came into it and thus hinder the growth of limestone composed of shells and skeletons of marine organisms. Therefore, it being assumed that the precipitation of phosphate at the ordinary rate was unhindered, that material would accumulate in a comparatively pure form. Perhaps the most important part of the whole problem relates to the manner in which the phosphatic substance was transferred from solution in the sea to the deposits at the bottom. The rather meager knowledge available on this subject suggests that the process was complex but is not sufficient to explain it in detail.

It is not to be denied that conditions essentially similar to those sketched in the foregoing paragraphs exist in many places to-day, without, so far as known, a noteworthy accumulation of phosphate. This fact, however, is not necessarily fatal to the hypothesis advanced, for the western phosphate deposits constitute an exceptional feature thought to be the result of conditions resembling those of to-day but intensified.

The bulk of the western phosphate beds is enormous. The known deposits as partly estimated contain 5,290,296,900 tons¹ of recoverable high-grade rock phosphate, which is evidently but a fraction of that originally contained in the region as a whole. In view of the knowledge available for this general region it seems not unreasonable to think that the area within a boundary roughly circumscribing the known phosphate lands (see Pl. IX), or between 50,000 and 100,000 square miles, was formerly underlain by deposits the equivalent of a continuous bed at least 5 feet thick and containing 30 per cent of phosphorus pentoxide. The fact of a great volume, however, needs no further explanation than a continued or extensive application of the process, whatever it was, that initiated the formation of

¹ Mansfield, G. R., Phosphate resources of the United States (paper read before Second Pan American Scientific Congress, Jan. 4, 1916).

this unique deposit. For example, to release sufficient phosphoric acid from its original matrix to form a bed of rock phosphate 5 feet thick, containing 30 per cent of phosphorus pentoxide, the decomposition of a layer of igneous rock of average composition (0.29 per cent P_2O_5),¹ about 500 feet thick, would be required. A similar layer of phosphate considered as a residue would require the leaching of about 350 feet of limestone of the average composition (0.42 per cent P_2O_5),² whether the limestone was dissolved as it accumulated, which is supposed to have been true for these deposits, or during a later period.

¹ U. S. Geol. Survey Bull. 591, p. 22, 1915.

² Idem, p. 23.

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DEPARTMENT OF THE INTERIOR

FRANKLIN K. LANE, Secretary

UNITED STATES GEOLOGICAL SURVEY

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**TUNGSTEN DEPOSITS OF NORTHWESTERN
INYO COUNTY, CALIFORNIA**

BY

ADOLPH KNOPF

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TUNGSTEN DEPOSITS OF NORTHWESTERN INYO COUNTY, CALIFORNIA.

By ADOLPH KNOPF.

INTRODUCTION.

The tungsten deposits of northwestern Inyo County, Cal., are west of Bishop, the largest town in Owens Valley. The mining industry centers at Deep Canyon, 8 miles from Bishop, where two mines opened on notable deposits of contact-metamorphic ore have recently been brought to the producing stage.

Deep Canyon traverses an isolated group of hills that project through the glacial and alluvial deposits at the base of the Sierra Nevada. Similar groups of hills farther south in Owens Valley are known by distinctive names, such as the Alabama Hills, and the name Tungsten Hills is here suggested for the group in which the principal tungsten deposits have been found. The average altitude of the hills is 6,000 feet, about 1,500 feet above the floor of Owens Valley, but they are dwarfed into insignificance by the mighty range behind them, which towers to altitudes of 13,000 feet.

Tungsten has been found also in the Sierra Nevada itself, southwest of Bishop. The tungsten-bearing area, so far as now known, extends from the north slope of the Tungsten Hills to the mouth of Shannon Canyon, 11 miles south of Bishop. The topography of the area is shown in figure 23, which is based on the maps of the Bishop and Mount Goddard quadrangles, both of which are on a scale of 1:125,000, or approximately 2 miles to the inch.

The mining conditions are favorable: the climate is good, water is easily obtained, transportation facilities are adequate, and an electric transmission line traverses the belt, so that power is readily available. Timber, however, is lacking. The tungsten area adjoins a rich agricultural district.

The tungsten deposits were briefly examined by me in June, 1916. To Mr. L. E. Porter I am especially indebted for courtesies during this examination. In preparing the present report I have drawn in part upon information obtained by me in 1913 during a reconnaissance of the Sierra Nevada slope between McGee and Haiwee creeks, west of Owens Valley, the results of which are now being prepared for publication by the Geological Survey.

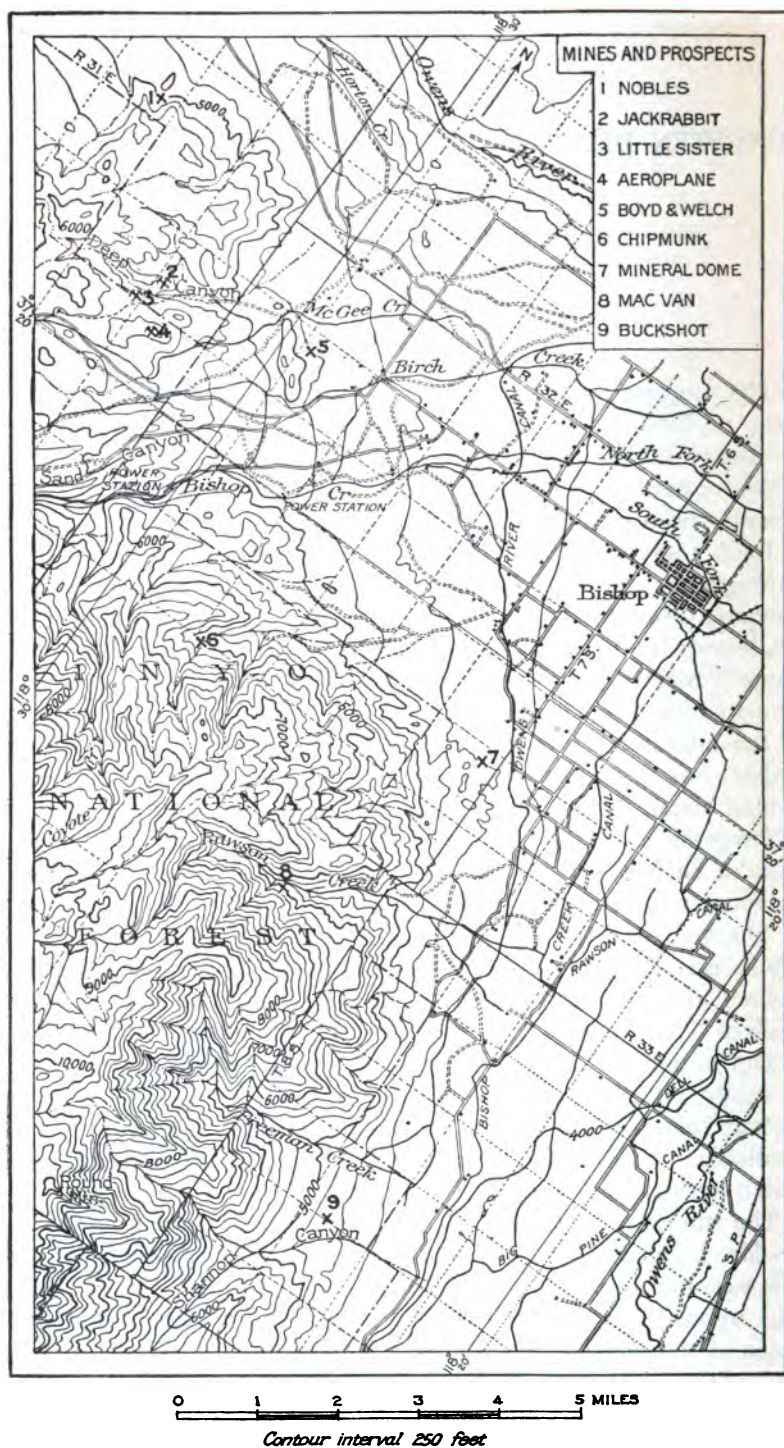


FIGURE 23.—Map of the tungsten-bearing area in northwestern Inyo County, Cal., and vicinity.

DISCOVERY AND DEVELOPMENT.

Tungsten ore was found in place in August, 1913, on the Jack-rabbit claim, near the present center of mining activity. The discovery was the result of careful prospecting, though it was eventually hastened by chance. Three partners, who were mining placer gold in Deep Canyon, found that the concentrates they obtained were difficult to clean because a heavy white mineral persistently accumulated in considerable amount with the gold. The troublesome material proved to be scheelite; and when its identity and value were known, search was soon begun to find it in bedrock. After all the quartz float in the area adjoining Deep Canyon, so it is reported, had been broken open in vain during the course of a year and a half, the scheelite was finally found in its rock matrix by J. G. Powning, who while out hunting recognized the long-sought mineral in an outcrop of garnet rock on which he had just shot a rabbit, an adventitious circumstance to which the discovery claim owes its name. The scheelite is here embedded in the blackish garnet rock as particles that are somewhat larger than are common in the ore bodies of the district, but it must be said that the scheelite is neither so prominent nor so obviously recognizable that it would have been found had it not been the special object of search. The discovery that the scheelite occurs in the garnet rock, however, reduced prospecting for tungsten to a very simple matter. The blackish garnet masses on the bare hills contrast noticeably with the prevailing gray and reddish granite and are therefore easily recognized; they were soon staked and then tested for tungsten. In this way ore was found at many places. As a rule the scheelite is so inconspicuous that the largest ore body, although it crops out prominently, was at first unfavorably reported on by competent engineers, from sheer failure to ascertain its trend and consequently its width and length.

Early in 1916, when the price of tungsten ore reached an extraordinary level, outside capitalists became interested in the development of the claims. The Standard Tungsten Co. acquired the Aeroplane group of six claims, work began on April 7, and by June 7 a mill having a daily capacity of 30 to 50 tons began crushing ore. During this short time roads were constructed, a tunnel and drifts were driven, a mill was built, and electric power was brought in from Bishop Creek. The Tungsten Mines Co., owning 14 claims, commenced development work on May 1 and by the middle of July had completed a 300-ton mill and had energetically explored its main ore body. About 125 men were being employed at these two mines at the time of visit. Below the mill of the Tungsten Mines Co. Deep Canyon widens out, and here the town site of "Tungsten City" has been laid out.

The development of the deposits on Deep Canyon has greatly stimulated prospecting for tungsten in the region west and southwest of Bishop. All garnetiferous rock is carefully examined and panned, with the result that scheelite-bearing rock has already been found at a considerable number of places. The development work done or in progress is small, however, except at the two producing mines.

OUTLINE OF GEOLOGY AND ORE DEPOSITS.

The prevailing rocks of the tungsten-bearing area are granitic. Two varieties occur in about equal amounts—the older a quartz monzonite and the younger a coarse, white granite practically barren of dark minerals. Both, however, belong to one epoch of intrusion and are parts of the great granitic masses that make up the east slope of the Sierra Nevada. They are of late Jurassic or early Cretaceous age. Besides these dominant granitic rocks there are basic modifications of them, such as quartz diorite, which are of small areal extent and commonly occur near the tungsten-bearing deposits. Narrow dikes of aplite also occur at some places.

Scattered through the granitic rocks are masses of sedimentary rocks ranging in size from a cubic yard to cubic acres. They are remnants of the roof that formerly extended as a continuous cover over the granites. Under this roof the molten granitic magmas came to place and cooled; the roof rocks became highly metamorphosed as a result of the high temperatures to which they were subjected and of the hot gases that permeated them. Strata of limestone occurring in these roof rocks were particularly susceptible to chemical reaction with the gaseous emanations, and where these emanations carried tungsten they fixed it as scheelite, together with garnet, epidote, amphibole, and quartz.

Erosion has since cut deeply into the region, destroying the continuity of the sedimentary roof and leaving as isolated remnants only those portions of it that projected down more deeply into the underlying granite.

The east slope of the Sierra Nevada, as has long been known, is a great fault escarpment whose main features were produced at the beginning of Quaternary time. West of Bishop it is extremely steep, being, in fact, surpassed at few places in height and precipitousness. A few miles to the south its general southeasterly alignment is offset 8 miles to the northeast. The Tungsten Hills are situated in the angle produced by this jog in the fault escarpment, and they appear to represent a fault block that has not been depressed as deeply as the remainder of the floor of Owens Valley. As the present summits of the Tungsten Hills probably coincide roughly with the general level of the batholithic contact of the granites and the rocks they

invaded, this subsidence accounts for the fact that this contact surface is from 3,000 to 4,000 feet lower here than it is in the Sierra Nevada proper a few miles to the west and southwest. These relations, though important to an understanding of the geologic history of the region, are hardly germane to the immediate problems of the ore deposits and will not be further considered here.

GENERAL GEOLOGY.

PREGRANITIC ROCKS.

CHARACTER AND DISTRIBUTION.

Although granitic rocks prevail in the tungsten area, sedimentary strata are scattered throughout the area in small masses, which range in size from a cubic yard to cubic acres. Economically they are the most important rocks, for they are the repositories of the tungsten ores. They are highly metamorphic, and their sedimentary character is therefore obscure. Originally they comprised in the main limestones, sandstones, and calcareous rocks, but as a result of the action of the heat and vapors that accompanied the granitic intrusions they were recrystallized, and a great variety of "contact rocks" or hornfelses was produced. The metamorphosed sandstones have largely retained their siliceous appearance, though specked with innumerable minute flakes of shimmering mica; the metamorphosed calcareous rocks—the calc-hornfelses¹—are light gray, fine grained, and notably heavy. Most of these metamorphic rocks require microscopic examination in order to determine their mineral make-up with certainty. Some of them have been thus examined and are here mentioned briefly. The rocks of main interest in connection with the tungsten deposits are the limestones, which have been either altered to garnet and allied silicates, with which accessory scheelite is associated, or rendered coarsely crystalline—marbleized, as it is termed. Such marbleized limestones occur in considerable volume in some of the masses. They still exhibit their stratification, and in all places examined they show that the rocks are standing on edge.

Scattered through some of the contact-metamorphic sandstone on the Aeroplane group of claims are conspicuous prisms of black tourmaline. Under the microscope the matrix of these prisms proves to consist of an intergrowth of quartz, muscovite, biotite, and graphite. This tourmaline, however, is the only occurrence of the kind noted in the district, and none is found in the tungsten ore bodies.

Sillimanite schist occurs in the western part of the sedimentary mass in which the largest tungsten deposit of the district is inclosed.

¹Such rocks are commonly called "lime-silicate rocks," but J. S. Flett in a systematic account of the hornfels group (*Encyclopedia Britannica*, 11th ed., p. 711, 1910) terms them "calc-silicate-hornfelses." This term is here abbreviated to calc-hornfelses.

The schist is associated with quartzite, siliceous grits and conglomerates, and limestones. It is a faintly schistose white rock, containing numerous particles of quartz; all in all it strongly resembles a dynamically altered rhyolite. Under the microscope it is found to consist of quartz, muscovite, and sillimanite. Some of the particles of quartz are much larger than the remainder, thus giving the schist its illusive porphyritic aspect. Sillimanite is scattered through the schist as a multitude of fibers in random orientation. From these determinations it is clear that the sillimanite schist was originally a siliceous grit. Its occurrence here is of some interest, inasmuch as the formation of sillimanite appears to require the highest temperature that prevails during contact metamorphism.

The calc-hornfelses include a number of varieties, ranging from dense fine-grained rocks resembling cherts or felsites to coarsely granular rocks. The fine-grained varieties consist of intergrowths of diopside, wollastonite, plagioclase, and garnet in various proportions; the coarsely granular varieties consist mainly of andradite garnet and epidote. An unusual variety, composed wholly of coarse vesuvianite, occurs near the Aeroplane ore body.

The age of these rocks is unknown, but they are believed to include strata ranging from Cambrian to Triassic. Cambrian fossils have been found in a small patch of limestones and sandstones, intruded by granite and aplite, west of the town of Big Pine and 4 miles south of the southernmost tungsten deposit yet known in the district. At the north end of the district considerable andesite, much altered by thermal metamorphism, occurs in a large remnant of pregranitic rocks. As andesites occur only with Triassic rocks in adjoining areas, where the stratigraphic record is unusually full, a Triassic age is suggested for this particular patch.

RELATION TO THE GRANITIC ROCKS.

The isolated bodies of limestone and associated contact-metamorphic rocks are remnants of a great mass of sedimentary rocks that once extended as a continuous roof over the granites. Under this cover the granites, working their way up into the lithosphere from unknown depths in the earth, came to place and, slowly cooling, assumed their characteristic coarsely crystalline state. The junction of the granites and roof rock is everywhere found to be of the kind peculiar to igneous contacts, and the position of the roof remnants in respect to the granites surrounding them is in nowise due to faulting.

The undersurface of the roof—that is, the contact of the sedimentary rocks and the underlying granite—was extremely irregular. It was angular in its local details, and in some places masses of sediments projected far downward in the granite, extending thus below the general level of the contact surface. Such masses, which have been

called "roof pendants," generally extend down nearly vertically in this region, owing to the fact that in its intrusion the granite tended to rift off blocks of the sedimentary strata parallel to their bedding, which, as already mentioned, is vertical. Some of the smaller sedimentary masses may indeed be such blocks that were thus rifted off and partly sunk in the molten granite. Erosion has now cut down below the general level of the contact surface; it has destroyed the original continuity of the roof and has reduced the roof to a number of isolated remnants, which appear as if scattered through the district in a highly haphazard manner. Erosion has cut down so deep, in fact, that only the tips of the masses that projected farthest downward into the granites have been preserved. These general relations and their effect on the distribution of the ore bodies are shown diagrammatically in figure 24. The thickness of the rock

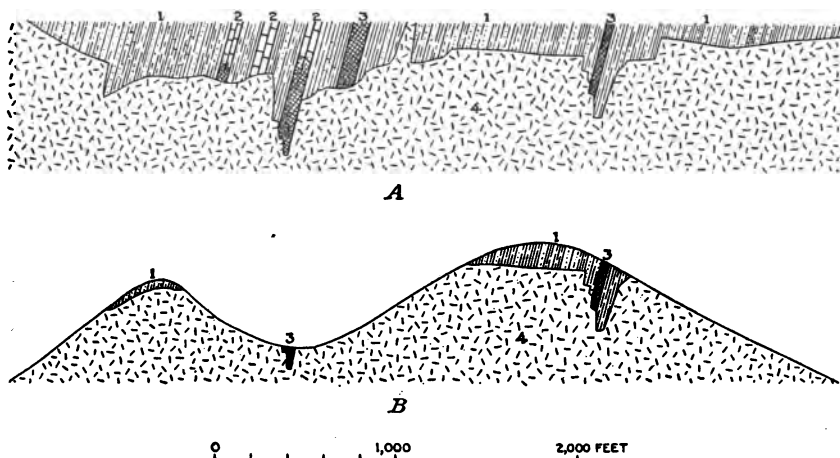


FIGURE 24.—Diagrammatic sections showing the relation of the metamorphic sedimentary rocks and ore bodies to the intrusive granitic rocks of the Tungsten Hills, Cal. *A*, At the time of intrusion; *B*, at the present time, when erosion has removed most of the rocks that formerly covered the granites and has evolved the existing topography. 1, Metamorphic sedimentary rocks; 2, limestone; 3, tungsten ore bodies; 4, granitic rock.

cover under which the granites were intruded is of course unknown and consequently is not shown in diagram *A*; what this thickness was, however, is unessential to the present discussion.

The depth to which the roof pendants extend in the granites that surround them is vital to the future prosperity of the tungsten-mining industry. Some of the masses, as indicated by their topographic relations, persist downward probably for at least 300 feet. As a rough generalization it is likely to prove true that the wider a roof pendant is at the surface the deeper it will be found to project into the granites.

Roof pendants are fairly abundant in the Sierra Nevada west of Owens Valley, especially in the higher parts of the range. Here their

spatial relations to the granites are clearly revealed in the great canyons and deep glacial cirques, which show that they project deeply into the granites, some of them extending 1,000 feet or more vertically downward. The largest roof pendant in this part of the Sierra is that between Middle and South forks of Bishop Creek, a few miles west of the tungsten area; it is not only the largest but appears also to project the most deeply into the granite, extending downward at least 2,500 feet. North of Middle Fork it is abruptly constricted, becoming only a few hundred feet wide, but despite its narrowness it persists north-westward for several thousand feet. The Bishop Creek gold mine is in the constricted portion of this roof pendant, and the ore body consists of a narrow band of quartzite carrying disseminated sulphides, principally pyrrhotite but also arsenopyrite, sphalerite, chalcopyrite, pyrite, and molybdenite. The remarkable persistence of this narrow roof pendant, both in length and depth, is of much interest, inasmuch as it suggests by analogy that some of the roof pendants in which the tungsten deposits occur may extend to considerable depths.

GRANITIC ROCKS.

Granitic rocks predominate throughout the tungsten-bearing area. Two varieties—quartz monzonite and granite—occur in about equal amounts. They differ notably in appearance and composition and are easily distinguishable. They are deeply weathered, especially in the main part of the tungsten area—the group of foothills west of Bishop. They have taken on a dull red or rusty orange color and in consequence contrast markedly with the brilliant white granites of the lofty Sierra high above the foothills. As the granitic rocks of the foothills and of the Sierra are portions of the same intrusive masses, this difference in appearance is manifestly due to differences in climatic environment and in the erosion to which they are subjected. In Owens Valley they are in a region whose rainfall is less than 5 inches a year and erosion is nearly at a standstill, whereas in the Sierra they are ceaselessly attacked by erosion. As a result the foothill granites suggest by their appearance that they are far more ancient than those of the Sierra; and to this illusive difference, it may be mentioned in passing, is doubtless due the belief, widely held in Owens Valley, that the foothills of the Sierra Nevada are the “oldest hills in the world.”

The quartz monzonite is the oldest of the granitic rocks. It is a coarsely granular aggregate of quartz, orthoclase and andesine in equal amounts, hornblende, and biotite. Rock of this kind, locally more or less modified, makes up a large part of the Sierra Nevada slope west of Owens Valley.

The younger of the two principal igneous rocks of the tungsten area is a coarse white granite. In the Tungsten Hills it occurs in about the same amount as the quartz monzonite, and to the south, in the Sierra

Nevada, as is excellently shown in Rawson Canyon, it occurs in large volume. It is composed almost wholly of albite, quartz, and orthoclase. Biotite in scattered flakes is the only dark mineral and makes up not more than 1 per cent of the granite. A specimen of the granite from Rawson Creek at an altitude of 6,000 feet was analyzed in part in the laboratory of the Geological Survey, with the following results:

Partial analysis of granite from Rawson Creek, Cal.

[R. C. Wells, analyst.]

SiO ₂	76.28
CaO.....	.47
Na ₂ O.....	4.72
K ₂ O.....	4.73

Specific gravity, 2.615.

Although quartz monzonite and granite predominate throughout the tungsten-bearing area considered as a whole, yet in the immediate vicinity of the main productive deposits—the Aeroplane and Little Sister—the prevailing igneous rock is quartz diorite. It is a rather dark variety, rich in biotite and hornblende, and is of medium to coarse grain. Under the microscope it is found that the component feldspar is andesine (Ab₆₀An₄₀) and that quartz occurs interstitially in moderate amount; hence the rock is termed quartz diorite.

The quartz diorite is clearly a local modification of the prevailing quartz monzonite, occurring only in proximity to the sedimentary rocks in which the tungsten deposits are inclosed. It is a basic contact facies, probably due to differentiation induced by the absorption of lime from limestones in the sedimentary roof rocks. Such contact facies do not occur near all the roof pendants, nor, on the other hand, are they in all places so homogeneous and so like normal plutonic rocks as is the quartz diorite on Deep Canyon. Adjoining some of the roof pendants, for example, are coarse hornblende-rich facies, which are irregular in grain and composition.

That the dioritic bodies surrounding inclosed masses of sedimentary rocks have resulted from the absorption of limestone is strongly suggested by the occurrence of similar dioritic fringes around inclusions in the orthoclase-albite granite of Rawson Canyon. Cubic miles of homogeneous granite are exposed in this profound canyon, but a few blebs of diorite, as they may be called, occur in the granite. When examined closely nearly every one of these bodies of diorite is found to inclose a core of garnet-epidote rock; aplite also occurs. It is manifest that the inclusions acted as centers that caused local differentiation of the surrounding granitic magma.

A few narrow dikes of aplite cut the sedimentary rocks of the tungsten-bearing area. They are fine-grained white rocks nearly barren of black minerals and are composed of quartz, microcline, albite, and scattered biotite or hornblende.

ORE DEPOSITS.

OCCURRENCE AND CHARACTER.

Tungsten deposits have so far been found in a belt 20 miles long extending from the north end of the Tungsten Hills to a locality within a few miles of the town of Big Pine. All the deposits are restricted to the isolated masses of metamorphic sediments embedded in the granitic rocks; and they are further restricted within these masses to the intercalated limestones.

The ores are of two main types, garnetiferous and micaceous. Those of the garnetiferous type strongly predominate and form the ore bodies now being worked. They consist largely of garnet, with which, however, some epidote is everywhere associated, and they carry scheelite as a subordinate constituent. Other minerals occur in minor quantities, and from place to place one or another of these is sufficiently abundant to be locally prominent. They include quartz, calcite, hornblende, pyroxene, and, as microscopic constituents, apatite and titanite. In one of the deposits, the largest yet found, quartz is somewhat more abundant than the associated garnet and epidote. Metallic minerals are extraordinarily rare in all the ore bodies: magnetite occurs sporadically in minute quantities, and the sulphides (pyrite, zinc blende, pyrrhotite, chalcopyrite, and molybdenite) occur in traces.

The garnet ranges from amber to dark brown in color, the deeper shades predominating. Under the microscope it generally shows complex birefringent patterns. It evidently varies in chemical composition, the refractive indices of different garnets ranging from 1.79 to 1.82, so that the average garnet may be considered as a variety about halfway between grossularite and andradite. As a rule the epidote is distinguishable from the associated garnet by its characteristic yellowish-green color and by its prismatic form. It appears to be generally a variety high in ferric iron; a specimen from the Aeroplane ore body gave $\gamma = 1.765$, corresponding to a variety containing approximately 15 per cent of ferric oxide. The amphibole, which as a whole is a subordinate component of the ores, is a fibrous variety of grayish-green color; under the microscope it proves to be deeply pleochroic in brown and green, and it is therefore referred to in this report as hornblende. The quartz, generally a very minor constituent, but in the Little Sister ore body highly abundant, is as a rule coarse grained and glassy. Under the microscope it resembles vein quartz, differing, however, in not uncommonly inclosing idiomorphic hornblende and pyroxene. It also incloses crystals of garnet and epidote. Calcite is generally a minor interstitial component, though in some ores it is fairly common and poikilitically incloses all the other constituents. All these minerals, including the scheelite,

are of essentially contemporaneous origin, and no definite sequence of crystallization is ascertainable.

The scheelite, a pure milk-white variety, is generally inconspicuous; in fact, in much of the best ore it is not certainly recognizable by the unaided eye. It has a fair cleavage, which distinguishes it from the milk-white quartz that occurs in some of the ore but which heightens its resemblance to the associated calcite. It is true that the trained eye can readily discriminate it from quartz and calcite by the refined distinctions of color, luster, and cleavage, but where the minerals occur in small particles this discrimination becomes impossible and it is necessary to pan the rock to determine its content of scheelite. Unlike the calcite in the ore, the scheelite rarely occurs interstitially between the garnet and epidote of the gangue, but it tends to form well-defined crystals; where it occurs in larger particles this tendency is readily apparent, and the scheelite at one prospect forms fairly good crystals as much as $1\frac{1}{2}$ inches in diameter.

The micaceous tungsten ores are not common, having been found in two prospects only. The magnesian mica phlogopite is the chief gangue mineral in the principal ore body at Nobles camp (see p. 247); and biotite and muscovite, together with magnetite, make up the gangue at the Mineral Dome prospect (see p. 248).

The ore bodies now being worked carry from 1.5 to 2 per cent of tungsten trioxide (WO_3). They range from 20 to 60 feet in width and from 150 to 260 feet in length. The greatest depth at which an ore body has so far been undercut is 200 feet. The vertical range of scheelite mineralization, as exposed by the erosion of Deep Canyon, is at least 700 feet; this range, although determined by the difference in altitude between two deposits, indicates that individual ore bodies may persist to depths of at least 700 feet, provided that the other necessary conditions hold good.

The ore bodies trend parallel to the strike of the inclosing strata. Where metamorphosed sandstone adjoins an ore body, as in the Aeroplane deposit, well-defined walls result and the ore breaks clean from the barren country rock.

Irregular masses of milk-white quartz, in places several feet thick, occur in some of the ore bodies, evidently as the final phase of mineralization. They contain sporadic prisms of epidote but no scheelite.

ORIGIN.

The tungsten ore bodies are clearly of contact-metamorphic origin. As is well known, deposits of the contact-metamorphic group result from the replacement of limestone, which supplies the calcium needed for the growth of the garnet and epidote. That the tungsten deposits of Inyo County originated in this way is not obvious at the larger

bodies, inasmuch as no limestone remains; if the deposits resulted from replacement, the limestone strata have been so thoroughly replaced that only a little calcite is left as an interstitial filling in the garnet rock. Some of the smaller deposits, however, give clear evidence as to the nature of the replacement. Near these deposits much marbled limestone remains, and at the edges of the deposits the garnet and epidote can be seen irregularly interfingering the surrounding white marble. Thin sections cut from marble adjoining these peripheral stringers of garnet show some wollastonite, a mineral nowhere found in the scheelite deposits themselves, and this development of wollastonite is probably due to the fact that at the edge of the deposits the metamorphosing solutions had become depleted in ferric iron.

The granitic rocks adjoin some of the ore bodies and have been profoundly altered along some of these contacts. The most notable alteration is that shown near the southeast end of the Little Sister ore body, where the adjoining diorite has been thoroughly altered to a distance of 5 feet from the contact. The transition from altered to unaltered diorite is abrupt. The altered rock differs conspicuously from the normal diorite, and the most obvious megascopic difference is perhaps its coarsely quartzose composition. Under the microscope it is found to be composed of quartz, monoclinic pyroxene, epidote, and a little residual hornblende. No scheelite appears to have been introduced during this alteration.

The orthoclase-albite granite adjoining the Mineral Dome tungsten deposit, which consists of biotite, muscovite, magnetite, and scheelite, has been altered by the development through it of silvery plates of muscovite at the expense of the potassium feldspar; in short, the granite has been transformed to a moderately micaceous greisen.

These metasomatic alterations of the granitic rocks adjoining the ore bodies show that the ores were formed at some time after the surrounding granites had consolidated. That tungsten mineralization followed the intrusion both of the quartz monzonite and of the granite is shown by the fact that the limestones embedded in the quartz monzonite and those in the granite are similarly mineralized. If the mineralization had followed only the later intrusion, fissures should be found leading to the limestones embedded in the earlier quartz monzonite, but such fissures have not been detected.

The minerals formed in the ore deposits indicate that the mineralizing solutions were active at high temperatures, probably so high that the solutions were in the gaseous state; and they show further that the solutions were rich in silicon, aluminum, and ferric iron, were poor in sulphur, and carried tungsten, which was fixed by the calcite in the limestones as calcium tungstate (scheelite).

COMPARISON WITH OTHER DEPOSITS.

The contact-metamorphic group of ore deposits has become well known in recent years. Lindgren¹ classifies the group into seven principal types, all of which, except the chalcopyrite and magnetite deposits, are distinctly rare. Tungsten deposits are not recognized in this classification.

Scheelite has been known for some time to occur as a minor constituent of contact-metamorphic rocks in Finland,² Japan,³ Alaska,⁴ New Mexico,⁵ and probably other localities. The scheelite deposit at Trumbull, Conn.,⁶ should probably be mentioned here. The scheelite occurs in a quartz-zoisite-epidote-hornblende rock, but the mine has never been commercially productive. In some of the Japanese deposits the scheelite, which is associated with garnet and chalcopyrite, forms crystals as much as 4 inches in diameter.

Only in recent years, however, have deposits of contact-metamorphic origin been found that carry sufficient scheelite to make them commercially valuable as tungsten ores. The earliest recognized ore body of this type appears to be that near Toy (formerly Browns), Humboldt County, Nev.⁷ This deposit became commercially productive late in 1915.⁸ Similar ore bodies have lately been found in the same county, and the Ragged Top mine commenced to produce ore in 1916. The field occurrence of these deposits has unfortunately not yet been described.

The tungsten ore bodies of northwestern Inyo County, Cal., are, as will be seen from the foregoing statements, important additions to the number of recognized contact-metamorphic scheelite deposits; and they appear destined to contribute notably to the tungsten production of the United States.

PRACTICAL DEDUCTIONS.

The persistence of the tungsten deposits in depth is the problem most vital to the future of the district. Because the deposits are restricted to limestones jutting down into the embedding granites and because of the mode of origin sketched in the preceding pages it is clear that in no deposit can ore be assumed with much confidence to extend below the deepest level opened. I do not mean to say

¹ Lindgren, Waldemar, *Mineral deposits*, p. 632, 1913.

² Trüstedt, Otto, *Die Erzlagertätten von Pitkäranta*: Comm. Geol. Finlande Bull. 19, p. 327, 1907.

³ Fukuchi, Nobuyo, *Mineral parageneses in the contact-metamorphic ore deposits found in Japan*: Beitr. Mineralogie Japan, No. 3, pp. 87, 89, 93, 94, 1907.

⁴ Knopf, Adolph, *Geology of the Seward Peninsula tin deposits, Alaska*: U. S. Geol. Survey Bull. 358, p. 38, 1908.

⁵ Lindgren, Waldemar, *The ore deposits of New Mexico*: U. S. Geol. Survey Prof. Paper 68, pp. 47, 52, 1910.

⁶ Hobbs, W. H., *The old tungsten mine at Trumbull, Conn.*: U. S. Geol. Survey Twenty-second Ann. Rept., pt. 2, pp. 13-22, 1901.

⁷ Hess, F. L., *Tungsten [etc.]*: U. S. Geol. Survey Mineral Resources, 1908, pt. 1, p. 724, 1909.

⁸ Hess, F. L., *Tungsten minerals and deposits*: U. S. Geol. Survey Bull. 652 (in press).

that individual ore bodies may not persist to depths of 700 feet or more, but until the continuity in depth is proved by exploration the uncertainty is great. This may sound axiomatic, inasmuch as the persistence of any ore body is more or less uncertain, but for the deposits here described the uncertainty is peculiarly great. The persistence of these deposits in depth depends on two factors—(1) the persistence of the limestone, the indispensable receptacle of the ores, and (2) the range through which the mineralization took place. Erosion has evaluated the second of these factors: it has disclosed the fact that the vertical range of mineralization was at least 700 feet, and there is no reason why the range may not have been considerably greater, although contact-metamorphic deposits, as must be recognized, are characteristically bumpy and irregular. The other factor is highly uncertain: the limestone originally necessary to form the ore may be cut off abruptly at any level below that now seen, owing to the unpredictable irregular nature of intrusive contacts. It is possible, however, that some sedimentary masses may project to considerable depths into the granite, as was pointed out on page 236. The conclusion that inevitably flows from these considerations is that it is not advisable to attempt to undercut the tungsten deposits by tunnels driven much below the lowest level on which ore has been proved to occur; in short, it is not advisable to drive the successively lower tunnels at vertical intervals greater than, say, 100 or 200 feet. It follows also that tungsten prospects situated in small, narrow roof pendants, however rich at the surface, are of very doubtful value; until they have been proved by actual exploration and an adequate amount of ore has been put in sight they will not justify the erection of mills.

Although the recent high prices of tungsten ores were the incentive for the rapid development of the district, nevertheless the principal operators believe that the mines can be profitably worked, even should the prices fall back to the levels prevailing before the European war—about \$6 a unit—a possibility that must of course be kept steadily in mind, in view of the enormous world-wide stimulation of the tungsten-mining industry. This confidence in the district is justified by the favorable mining conditions and the amount of ore indicated.

The milling capacity of the district is sufficient, if utilized in full on ore of the grade now worked, to make the annual output of the district equal that of the whole annual output of the United States before the war. Manifestly this rate of production would speedily deplete the known ore bodies, and it appears doubtful whether so large an output could be maintained for a number of years unless other ore deposits in addition to those now worked were found and developed extensively.

Geologic conditions similar to those at Deep Canyon prevail over a wide area along the east slope of the Sierra Nevada. The bodies of garnet rock scattered through the great granite masses that make up this slope are being carefully examined and panned for scheelite by the prospector, and as a result other ore bodies will doubtless be found.

MINES AND PROSPECTS.

The two operating mines and the prospects that were examined during the time at my disposal are described in the following pages, but these descriptions by no means include all the prospects in the district. The locations of the mines and prospects here described are shown in figure 23.

AEROPLANE GROUP.

The Aeroplane group of six claims is owned by the Standard Tungsten Co., the pioneer company in the district. The claims are on the south side of Deep Canyon, and the principal ore deposit is near the top of the hill on which is situated the 6,045-foot bench mark of the United States Geological Survey. The mill is in the canyon about 600 feet below the ore body. It is equipped with a jaw crusher and rolls, and its capacity at the time of visit was from 30 to 50 tons a day, but this is now being increased to 100 tons. During the initial operation of the mill the ore was crushed to 8-mesh and concentrated upon an Isbell table. By this procedure, however, about 35 per cent of the scheelite was lost in the tailings, and the concentrates were not clean, as it proved to be difficult to separate the heavy garnet, whose specific gravity is near 3.8, from the scheelite (specific gravity 6). The ore was then crushed to 14-mesh in order to set free all the scheelite contained in it, and the operation of the table was also changed.

The main tungsten deposit is cut at a depth of 30 to 40 feet by a tunnel 100 feet long. The ore is quarried at the surface and dumped through a grizzly into a chute extending down to the tunnel; from the mouth of the tunnel the ore is dragged in two-wheeled sleds to the mill. It is proposed, however, to build eventually a tramway 1,700 feet long, from the tunnel to the mill.

The prevailing country rock is a medium-grained dark-gray quartz diorite containing much hornblende and biotite. Embedded in this, between the mill and the main ore body, are masses of sedimentary rocks, which were originally sandstones and limestones but are now highly recrystallized as a result of the metamorphic action of the intrusive diorite. Some of these rocks—contact rocks or hornfelses—have been examined microscopically in order to determine their mineral composition. For example, one of the metamorphosed sandstones, occurring on the lower slope of the hill shows conspicuous prisms of black tourmaline and under the microscope is found to

consist of abundant muscovite together with biotite and graphite, in addition to the original detrital quartz. The rocks at the summit of the hill, which inclose the main ore body, are mainly calc-hornfels and limestones. They strike north as a rule and stand on edge. They are cut by a few dikes of aplite, and on the south they are intruded by coarse white granite.

The main ore body is 150 feet long and ranges from 20 to 30 feet in thickness; it averages 1.5 per cent of tungsten trioxide. The ore is scheelite inclosed in a gangue consisting mainly of garnet and epidote. The scheelite appears to be evenly scattered throughout the ore in small particles, few of which exceed a quarter of an inch in size and most of which are much smaller. Although garnet and epidote predominate in the gangue, hornblende is present subordinately, and calcite, quartz, pyroxene, apatite, and titanite occur in minor quantities. The only metallic minerals in the ore are black zinc blende and pyrite; they occur in insignificant amounts only, but as the ore at the surface is somewhat oxidized they may become slightly more abundant in depth.

The ore body trends north and stands nearly vertical, following the stratification of the inclosing rocks. The east boundary is well defined, being marked by a "wall," though it is not a wall in the usually accepted meaning of the term. The wall rock, locally known as porphyry, is a thermally metamorphosed sandstone, consisting largely of an aggregate of quartz grains, throughout which there is a new growth of muscovite and biotite. This siliceous rock was evidently not susceptible to replacement by garnet, epidote, and scheelite and hence now forms a wall to the ore body.

The ore zone ends on the north against fine-grained dense calc-hornfels, resembling chert or felsite. A variety of metamorphic rock made up chiefly of vesuvianite occurs here also. These rocks are cut by a granite dike interlaced with stringers of coarse white quartz. In places the quartz carries crystals of epidote and the granite is altered to a mass of epidote prisms. As exposed at the surface the ore-bearing zone extends farther south beyond the ore shoot, and in the drift on the tunnel level the ore extends somewhat farther south in this zone than it does on the surface. Considerable quartz occurs in the ore zone in places, swelling to masses several feet in size; it carries no scheelite, however.

In addition to the main tungsten deposit, 5 feet of rich ore was crosscut at the portal of the tunnel; in this the scheelite has a sort of porphyritic habit, owing to its occurrence in relatively large distinct crystals. Some isolated masses of scheelite-bearing contact rock have been found several hundred feet north of the main ore body, at an altitude 250 feet lower.

As exposed by erosion the sedimentary rocks that inclose the main ore body have an extreme vertical range of 250 feet; they may project

down into the granite this much more in their whole bulk or only parts of the mass may project downward, and this downward-projecting portion may not include the ore-bearing zone. In view of these uncertainties, it is not advisable, in exploring the ore zone in depth, to drive the successive tunnels at vertical intervals greater than 250 feet. The relief between the mill and outcrop of the ore body makes it easy to attain a depth of 600 feet on the ore body by a tunnel, but in view of the origin of the deposit it would be highly incautious to attempt this until more development work in depth has been done.

TUNGSTEN MINES CO.'S CLAIMS.

The Tungsten Mines Co. owns 14 claims, which lie north of those of the Standard Tungsten Co. Development of the property began on May 1, 1916, and was pushed with great vigor, 90 men being employed. Mining work was centered on the Little Sister claim, on which the largest and most easily workable ore body is situated, and the construction of a mill of 300 tons daily capacity was begun. The mill, which was completed by the end of July, is equipped with jaw crushers, rolls, and tables and is planned to operate on a product crushed to 14-mesh. A tramway connects the lower tunnel on the Little Sister claim with the mill, and another tramway is being built to the workings on the Jackrabbit claim, where a body of ore is also indicated.

The main ore deposit on the Little Sister claim is 260 feet long on the surface. It is opened up by two tunnels, one at a depth of 60 feet and the other at 200 feet. A shaft has been sunk in ore from the surface and connects with the upper tunnel. The ore is not conspicuously different from the inclosing country rock, nor in general is its content of scheelite certainly recognizable without panning. The grain of the ore-bearing rock is somewhat coarser, however, than that of the barren rocks; this difference is well shown at the north-west end of the ore body, where dense aphanitic calc-hornfels appear—rocks that, as Mr. Cooper Shapley, the superintendent, expresses it, are “too tight for ore to live in.” A small horse of similar calc-hornfels occurs in the ore body 20 feet southeast of the shaft; it is a heavy fine-grained white rock, which in microscopic section is found to be made up of garnet, pyroxene, and wollastonite.

The upper tunnel at the time of visit had crosscut 60 feet of ore without reaching the farther limit of the ore body. The lower tunnel, according to a late report, has cut the ore body 390 feet from its portal. The ore across the 60-foot crosscut in the upper tunnel averages 2 per cent of tungsten trioxide, but in the last few feet it averages between 3 and 4 per cent.

The ore body is near the east margin of a relatively large mass of metamorphosed sedimentary rocks embedded in quartz diorite. These rocks consist of limestone, calc-hornfelses, sillimanitic quartzite,

siliceous conglomerate, and metamorphic shale. They stand vertical. Some narrow dikes of aplite have been injected into them parallel to the stratification. On the summit of the knob, a few hundred feet west of the mine, an intrusion breccia of granite filled with sharply angular fragments of metamorphic sedimentary rock is well shown. The cover of sedimentary rocks has been stripped off the diorite in places, showing that locally it is very thin.

The ore body begins at the southeast corner of the roof remnant and extends 260 feet N. 55° W. At its southeast end it adjoins the diorite, which here has been intensely altered to a quartz-pyroxene-epidote rock, but as it extends northwestward it diverges from the contact, whose trend is slightly more northerly.

The ore crosscut in the upper tunnel consists of scheelite in a gangue of quartz, garnet, and epidote. Black zinc blende, pyrite, and molybdenite occur in minute amounts. The quartz, which is coarse and glassy, dominates in the gangue, giving the ore a characteristic siliceous appearance, and in this respect the ore differs from the other ores of the district. Minor constituents, recognizable as a rule only under the microscope, however, are hornblende, pyroxene, calcite, and apatite. The ore exposed in the upper tunnel is probably somewhat more coarsely granular than the general run of ore along the outcrop. The larger part of the outcropping ore is rather fine grained, and the scheelite it contains is extremely inconspicuous, even in ore rich in this mineral. Such ore resembles so much barren country rock—a resemblance that caused the deposit to be under-rated earlier in the history of the district, as only by a systematic campaign of sampling and panning were its course and dimensions determined.

A body of good tungsten ore 10 feet wide crops out about 100 feet southwest of the main deposit but has not yet been prospected.

The company has also done some work on the Jackrabbit claim, where tungsten ore was first found in place in the district. The developments consist of a number of trenches, a shaft, and a short tunnel and drift. The ore differs widely from that on the Little Sister claim, being composed largely of garnet, with accessory scheelite. Minor components are hornblende, quartz, calcite, and pyroxene, any one of which in places may become prominent; at one of the lower trenches, for example, hornblende is a conspicuous component of the garnetiferous rock.

The scheelite-bearing garnet rock at the portal of the tunnel is coarse grained, and the garnets are particularly well crystallized. In the drift beds of garnet rock 8 to 12 inches thick alternate with white calc-hornfels; they strike N. 70° E. and dip 70° S.

The ore body on the Jackrabbit claim is in a mass of metamorphic sedimentary rocks, largely garnetized, separate and distinct from that containing the ore body on the Little Sister claim.

NOBLES CAMP.

At the north end of the Tungsten Hills is a group of claims owned by A. W. Nobles, one of the original three locators in the district. These claims cover one of the largest masses of metamorphosed sedimentary rocks in the hills. The rocks are of many kinds but include much limestone. Some andesite, altered by thermal metamorphism, is associated with the sedimentary rocks. To the southeast coarse white granite is the country rock.

Very peculiar tungsten ore is exposed at the lowermost open cut, where 8 feet of ore, averaging, it is reported on good authority, 4 per cent of tungsten trioxide, has been crosscut. The deposit is a few feet from the contact of the granite and the metamorphic sedimentary rocks in which it is inclosed. The scheelite occurs in a roughly banded rock composed chiefly of dark mica, which the microscope shows is the magnesian variety phlogopite. With the mica are associated a little epidote, quartz, and apatite. In the ore body are small horses of dense fine-grained calc-hornfels.

Southeast of the open cut just described a tunnel, which had been driven a number of years ago to prospect a supposed gold deposit, cuts another belt of scheelite-bearing rock. A drift has been driven on this deposit and some cupriferous tungsten ore, consisting of chrysocolla, quartz, and scheelite, has been taken out. Rock from a shallow pit above the tunnel, supposedly on the outcrop of the deposit cut in the tunnel, is stained by a yellow vanadium mineral.

CHIPMUNK PROSPECT.

The Chipmunk prospect was located in April, 1916. It is at an altitude of 6,000 feet in a nameless canyon in the Sierra Nevada slope, the second canyon south of Bishop Creek. The property consists of nine claims in two groups.

The rock of the lower part of the canyon is the coarse white granite, but that in the vicinity of the prospect is gray quartz monzonite, consisting of quartz, andesine, orthoclase, and biotite. The scheelite deposits occur in a block of sedimentary rocks, largely limestone, embedded in the quartz monzonite. The sedimentary mass is 200 feet wide at its widest part, is several hundred feet long, and as shown by the deep canyon on the northwest, extends downward at least several hundred feet. The limestone, which is marbleized, is cut by a few narrow dikes of aplite.

Scheelite occurs at the southeast end of the sedimentary mass in scattered shoots. The ore is as a rule highly garnetiferous but contains also epidote, hornblende, calcite, and quartz. Scheelite is irregularly distributed through this rock in comparatively large particles, which commonly show the double pyramidal form characteristic of the mineral. Crystals as much as 1½ inches long have been found.

In general the scheelite occurs in larger individuals in this prospect than in any other deposit in the district. Metallic minerals occur in trivial amount and include magnetite, pyrite, pyrrhotite, sphalerite, and chalcopyrite.

MINERAL DOME PROSPECT.

The Mineral Dome prospect is 3 miles south of Bishop. The ore-bearing zone here consists of a belt of garnetiferous rock 600 feet long and in places at least 50 feet wide. It lies at the foot of a granite ridge and extends along the edge of the alluvium and the granite. Granite sand and immense granite boulders have slid over the ore-bearing zone and nearly conceal it.

The ore-bearing zone trends westward. Near its east end the zone is cut by a short tunnel, which penetrates the orthoclase-albite granite bounding it on the south. The granite has been somewhat altered by the growth of muscovite through it, and is slightly seamed with micaceous veinlets; such granite is said to pan gold. The tunnel shows, besides garnetiferous rock and limestone, a 4-foot layer of micaceous tungsten ore. The ore layer dips southward at a low angle, terminating against the granite. The ore consists of scheelite in an intergrowth of biotite, muscovite, magnetite, quartz, and epidote. Some chrysocolla and chalcopyrite occur in places in the ore.

The other development work done on the prospect consists of three trenches dug across the width of the ore-bearing zone. They expose garnetiferous rock locally rich in scheelite.

MACVAN CLAIM.

The MacVan claim, located in May, 1916, is $1\frac{1}{2}$ miles up the canyon of Rawson Creek. The general country rock is coarse white granite, within which are some small bodies of diorite. In the heart of these diorite masses are small inclusions of metamorphosed limestones, most of them not over a few cubic yards in volume. The metamorphic rock consists of garnet and epidote and carries a little quartz and scheelite of sulphur-yellow color.

BUCKSHOT PROSPECT.

The Buckshot prospect, on the north side of the mouth of Shannon Canyon, is 11 miles south of Bishop. A knob of bedrock, about 300 square feet in areal extent and 30 feet high, projects here through the alluvium at the base of the Sierra. It had been slightly prospected for gold in years gone by.

The knob consists of a series of coarsely crystalline limestones standing on edge and abutting on the north against a rudely crescentic outcrop of granite. Along this contact there has been intense

metamorphism, resulting in the formation of epidote-hornblende rocks. The granite is as a rule highly epidotized, and in places it is impossible to distinguish altered limestone from altered granite.

The ore, which in places is of extremely high grade, consists of scheelite, of rather idiomorphic habit, in a gangue composed principally of epidote, hornblende, calcite, and quartz. Under the microscope chlorite, pyroxene, garnet, magnetite, titanite, and apatite are found to occur subordinately. Pyrite is a rare constituent. Between the ore and the granite there are in places irregular masses of epidote-bearing quartz, which carry sporadic scheelite. Two shoots of ore are recognizable; they extend into the limestone for a distance of about 20 feet from the contact.

The Buckshot prospect is near the southernmost limit of the tungsten belt, so far as now known.

SUMMARY.

Tungsten deposits were found in northwestern Inyo County, Cal., in 1913 but remained practically unknown until the spring of 1916, when they began to be energetically developed. By midsummer two mills, having a total daily capacity of 400 tons, had been completed and were in active operation.

The ore consists of scheelite associated mainly with garnet, epidote, and quartz. The country rock is prevailingly granitic, but in it are isolated masses of limestone which became mineralized shortly after the granitic rocks were intruded. The limestones were altered to masses of garnet carrying subordinate scheelite by the metallic vapors then given off, and these altered rocks are the tungsten deposits now under exploration. The ore bodies that are being mined are from 20 to 60 feet wide and from 150 to 260 feet long. They carry from 1.5 to 2 per cent of tungsten trioxide (WO_3). The area in which scheelite-bearing deposits have been found roughly forms a belt 20 miles long, but it is likely that the prospecting now going on will extend the dimensions of the field.

These deposits, like those discovered in recent years in Humboldt County, Nev., belong to the contact-metamorphic class, a well-known source of copper and iron but not widely recognized as a possible source of tungsten.

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